**P. LANE AND ASSOCIATES LIMITED**
Environmental Consultants

Project E-229

# HEAVY METAL REMOVAL FROM GOLD MINING AND TAILINGS EFFLUENTS USING INDIGENOUS AQUATIC MACROPHYTES

(Phase 1)

## FACTORS AFFECTING PLANT BIOMASS AND TISSUE CONCENTRATIONS OF ARSENIC AND MERCURY AND THE DISTRIBUTIONS OF PLANE COMMUNITIES ON GOLD TAILINGS IN NOVA SCOTIA

# Heavy Metal Removal from Gold Mining and Tailings Effluents using Indigenous Aquatic Macrophytes

(Phase 1)

## Factors Affecting Plant Biomass and Tissue Concentrations of Arsenic and Mercury and the Distributions of Plant Communities on Gold Tailings in Nova Scotia

E-229

Final Report

by

P. Lane and Associates Limited

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## ABSTRACT

Gold mining has been conducted in Nova Scotia since the mid-1800's. Much of the province is underlain by rocks of the Meguma Group of slates (Halifax Series) and greywackes (Goldenville Series). These formations often have gold and arsenic associated with them in the form of arsenopyrite. A Nova Scotia mining company plans to reclaim gold from seven abandoned tailing sites along the Black Brook near Oldham, Nova Scotia. The recovery of gold in this area will expose tailings to oxidizing conditions, resulting in serious ecological consequences to aquatic ecosystems downstream of these sites. A previous study of Black Brook showed that it was a stressed ecosystem with several aquatic plant species exhibiting high concentrations of mercury and arsenic. Diversity of aquatic fauna was low, and several fish species exhibited histopathological abnormalities related to heavy metal toxicity and low pH.

The purpose of this study (Phase 1) was to characterize mineralogical and biological conditions of the site to establish an ecological understanding for using aquatic macrophytes to remove heavy metals from the proposed tailings excavations. Data were collected from 123 sampling stations distributed along 17 transects which crossed the tailings pond roughly perpendicular to Black Brook.

Very high values of mercury were found ranging from 2.1 to 9.0 ppm in all samples. This is at least two orders of magnitude higher than the host rock. Arsenic values ranged from 25 ppm to 2.4 weight percent (24000 ppm) and were consistent with being bound in the mineral arsenopyrite. The vegetation data were sorted into groups of similar species composition by using cluster analysis. This methodology provides an objective partitioning of the study area into distinctive plant communities which can then be mapped relative to the transects. Data pertaining to the physical environment of the tailings (arsenic and mercury concentrations, percent soil organic matter content, thickness of organic matter layer in the soil, depth to water table, and the vegetation data) were subjected to discriminant analysis.

In preparation for possible initiation of the Phase 2 study which will investigate the capability of aquatic and semi-aquatic macrophytes to remove arsenic and mercury from solution, twelve species of plants have been propagated in the laboratory.

# RESUME

L'exploitation de gisement aurifères a commencé vers le milieu du 19° siècle en Nouvelle-Ecosse. La majeure partie de la province est couverte par les ardoises du groupe Meguma (séries Halifax) et par les grauwakes des series Goldenville. Ces formations renferment souvent de l'or auquel est associé de l'arsenic sous forme d'arsenopyrite. Une compagnie minière Néo-Ecossaise se propose de récupérer l'or des résidus miniers abandonnés à sept emplacements le long du ruisseau Black, près d'Oldham en Nouvelle Ecosse. L'extraction de l'or dans cette région s'effectue en oxidant les résidus miniers, ce que entraine de sérieuses conséquences écologiques pour l'enviromnent aquatic à l'aval des sites d'exploitation. Une étude précédente du ruisseau Black a demontré que l'écosystème a été sévèrement affecté; plusieurs plantes aquatiques exhibe de fortes concentrations de mercure et d'arsenic. La diversité de la faune aquatique est faible et plusieurs espèces de poisson montrent des signes histopathologiques d'intoxication par les métaux lourds.

L'objectif de cette étude (Phase 1) était de caractériser les conditions biologigues et minéralogines du site, et de déterminer le cadre environnemental préalable à l'utilisation de macrophytes aquatiques pour retirer les métaux lourds qui seront libérés par l'oxidation des résidus miniers. Les données ont été recueillies à 123 stations d'échantillonnage réparties en 17 transects traversant les étangs de résidus, perpendiculairement à l'axe du ruisseau Brook.

L'étude a permis de détecter de très fortes concentration de mercure allant de 2.1 à 9.9 ppm dans tous les échantillons analysés. Les concentrations sont au moins 2 ordre de grandeur supérieures à celles de la roche mère. Les niveaux d'arsenic sont de 25 à 2400 ppm (2.4% en poids), ce qui s'explique par leur liaison à l'arsenopyrite,. Les données sur la végétation ont été classées par groupes d'espèces semblables à l'aide d'une analyse par grappes. Cette methode permet une répartition objective des diverses communautés de plantes dans le territoire à l'étude, lesquelles peuvent être cartographiés par rapport aux transects. Les données s'appliquant à l'environnement des résidus miniers (concentrations de mercure et d'arsenic, contenu de matiere organique dans le sol, épaisseur de la couche de matière organique dans le sol, profondeur de la nappe phréatique et les données sur la végétation) firent l'objet d'une analyse de discriminant.
La Phase II de l'étude est une investigation de la tendance des plantes semi aquatique macrophytes à retenir dans leurs tissus l'arsenic et le mercure en solution dans l'eau. Pour cette seconde phase, douze espèces de plantes ont été sélectionnées et cultivées en laboratoire.

# 1.0 INTRODUCTION

Much of the Province of Nova Scotia is underlain by rocks of the Meguma Group of slates and greywackes. In the mid-1800's gold deposits were discovered in quartz veins in rocks of the Meguma Group. Gold production of over 1,000,000 troy ounces from intermittent work in over 50 gold districts throughout southern Nova Scotia continued until the 1940's. Part of the legacy of these mining operations are a large number of tailings deposits containing high concentrations of arsenic derived from the arsenopyrite which is the main sulphide mineral occurring with the gold. Tailings deposits produced before the early part of this century often contain high concentrations of mercury derived from the mercury amalgamation technique used to separate the gold from the tailings. The milling process used in Nova Scotia resulted in relatively high loss of mercury to the tailings. The grades were often quite high, resulting in considerable gold in the tailings even when recovery rates were high. Recently it has become potentially profitable to reprocess the tailings from these old mine sites to extract the residual gold.

One such tailings site is at Oldham, Nova Scotia. The tailings at Oldham are divided into seven separate deposits spread along the course of Black Brook, a small stream stressed by both acid drainage within the watershed and arsenic derived from the tailings deposits. Black Brook eventually empties into the Shubenacadie River, which provides drinking water for several communities and which supports commercial and sport fisheries. A Nova Scotia mining company plans to reclaim tailings from the largest of the tailings deposits exposing them to oxidizing conditions leading to increased losses of arsenic and mercury from the site, possibly resulting in serious consequences for aquatic ecosystems downstream.

A two-phase study was commissioned to characterize the mineralogical and biological conditions of the site (Phase 1) and to investigate the feasibility of using aquatic and/or semi-aquatic macrophytes to remove arsenic and mercury from the waters draining the excavation site (Phase 2). In detail, the Phase 1 study was designed to address the following objectives:

1) to conduct a geological survey of a tailings site including a description of arsenic and mercury in tailings, with depth profiles;

2) to describe the water quality of the study area including the quality of groundwater and receiving waters; and

3) to describe the plant communities associated with the study area. This objective includes mapping of plant communities, determination of arsenic and mercury concentrations in plants and measurement of the biomass of dominant terrestrial and aquatic plants.

In addition, we have attempted to ascertain what physical features of the tailings influence the species composition and productivity of the plant communities on the existing tailings deposits. This information is useful in selecting species to recolonize the remaining tailings area following excavation of the more valuable tailings.

## 2.0 METHODS

### 2.1 Sampling Plan

A field reconnaisance of the study site was conducted in early July 1988. At that time biological and geological personnel involved in the project inspected the tailings area and devised a sampling program which integrated biological, geological and water chemistry sampling. In this way the interaction of the physical and biological systems on the site could be ascertained.

The sampling methodology chosen involved a series of 123 sampling sites distributed along 17 transects which crossed the tailings pond roughly perpendicular to Black Brook (Figure 1). Biological data were collected at all sampling stations, and geological data were collected from a subset of 37 of the sampling sites. Six piezometers were installed in the tailings area to collect groundwater samples for chemical analysis and to permit monitoring of groundwater fluctuations during the field season. At each piezometer site, biological and geological data were collected. Surface water chemistry data were collected at five sampling sites upstream, within and downstream of the tailings.

### 2.2 Tailings Composition

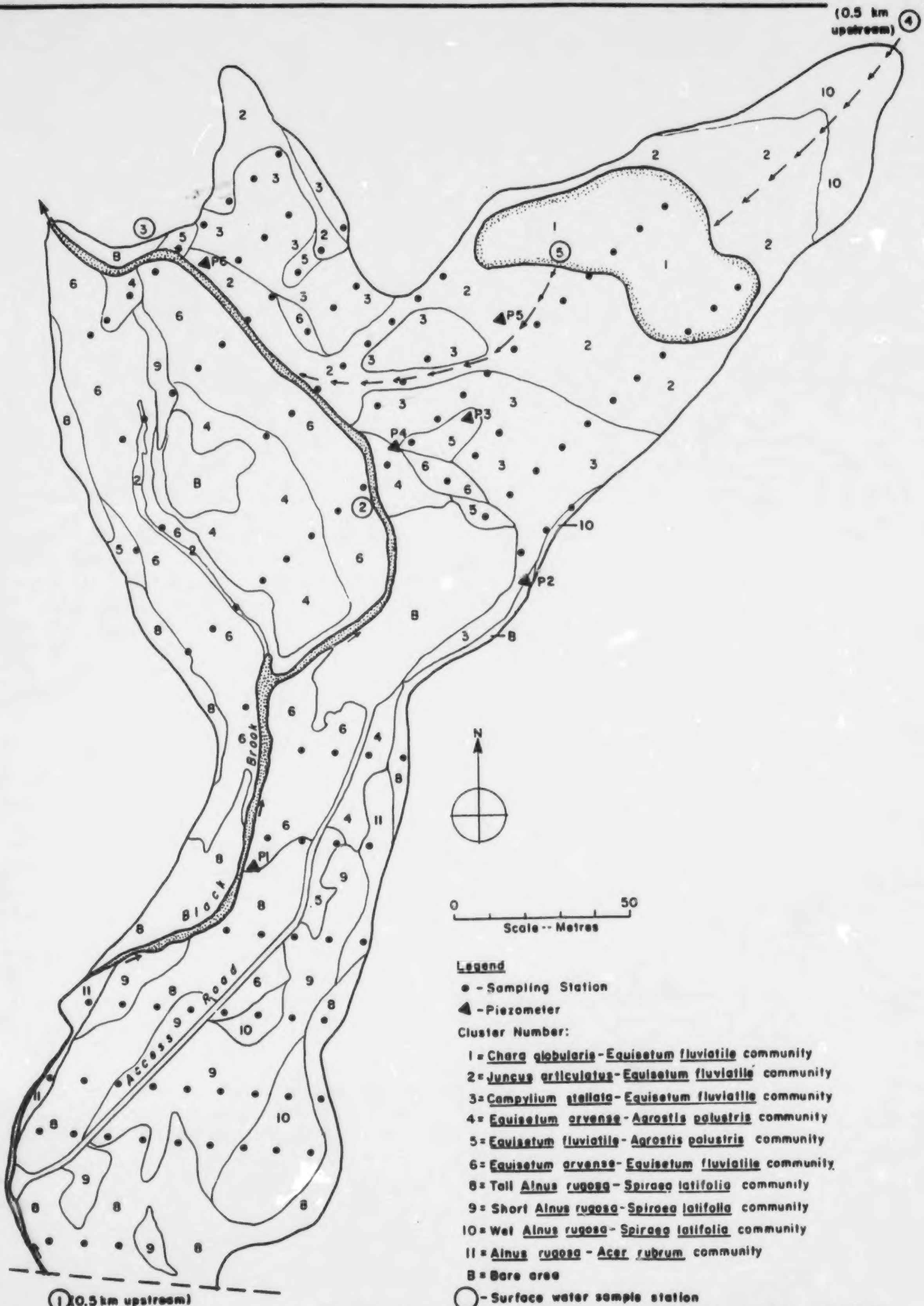
At each geological sampling station a 70 cm hole was dug and samples of each distinctive stratum were collected. An average of four strata were found in each hole, for a total of 140 samples analyzed.

#### 2.2.1 Minerology

Mineral identification was done using a petrographic microscope of polished grain mounts in reflected light and examination of loose grains under a binocular microscope. Grain mounts were prepared of bulk samples, and grain mounts were also examined of mineral separates made by Franz magnetic separator and by heavy liquids (SG = 2.7).

#### 2.2.2 Chemical Analysis

Analyses for arsenic and mercury were performed by the Technical University of Nova Scotia Mineral Engineering Centre. Samples to be analyzed consisted of two 10 cm x 6 cm cylindrical cores taken from the surface of the soil taken at each of the 123 sampling sites. The two cores from each site were pooled then sifted through a number 4 sieve (4.75) mm). The material which did not pass the sieve consisted of partially decayed organic matter. This material was dried, weighed and recorded as the coarse organic matter fraction. No further chemical analysis was done on this fraction. The material which passed through the sieve was separated into sink and float fractions by a series of distilled water rinses with agitation. Both fractions were rinsed repeatedly to ensure good separation. The sink fraction thus consisted of particles with a specific density of more than 1.0 (sand and silt)). The float fraction contained the less dense particles and was


(0.5 km upstream) ④
③
②
⑤
① (0.5 km upstream)
P1
P2
P3
P4
P5
P6
Black Brook
Access Road
N
0
50
Scale -- Metres
Legend
● - Sampling Station
◀ - Piezometer
Cluster Number:
1 = Chara globularis - Equisetum fluviatile community
2 = Juncus articulatus - Equisetum fluviatile community
3 = Campylium stellata - Equisetum fluviatile community
4 = Equisetum arvense - Agrostis palustris community
5 = Equisetum fluviatile - Agrostis palustris community
6 = Equisetum arvense - Equisetum fluviatile community
8 = Tall Alnus rugosa - Spiraea latifolia community
9 = Short Alnus rugosa - Spiraea latifolia community
10 = Wet Alnus rugosa - Spiraea latifolia community
11 = Alnus rugosa - Acer rubrum community
B = Bare area
○ - Surface water sample station

OLDHAM TAILINGS VEGETATION MAP

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FIGURE 1

primarily composed of clay and organic materials. Both fractions were dried at 80°C overnight then weighed.

The sink and float fractions for each site were analyzed for total (acid extractable) and available (water soluble) arsenic and mercury. Uncrushed samples analyzed for acid extractable arsenic were leached with 30 ml HCl, 10 ml $HNO_3$, 10 ml HF and 5 ml $HClO_4$, evaporated to dryness and dissolved with 10 ml HCl and 50 ml distilled water. The samples were filtered then into a 100 ml flask. An aliquot was placed into a generation bottle and measured amounts of potassium iodide (KI) stanous chloride SnCl, HCl and water were added. The mixture was allowed to stand to ensure complete reduction of all arsenic present to $AS^{3+}$. Granular zinc was then added and the arsenic generated was led through a lead acetate impregnated filter (to remove sulfides) into a silver diethyldiothiocarbonate solution where arsenic was trapped as a complex ion. The absorbance of this solution was then measured with a spectrometer. To assure complete digestion a sample was submitted crushed. No significant differences were found between crushed and uncrushed samples. Sample handling was kept to a minimum and crushing was not done. To determine water soluble arsenic one gram samples were stirred for 1/2 hour at room temperature with 50 ml distilled water. The samples were filtered and treated as above.

Samples (0.5 g) analyzed for acid extractable mercury were placed in 38 x 200 mm test tubes and digested with 20 ml concentrated $HNO_3$ and 1 ml concentrated HCl in a water bath, at 90°C for two hours after predigestion overnight at room temperature. Concentrations were determined by cold vapor atomic absorption after treatment with stanous sulphate. Visual inspection of mercury solutions was undertaken to verify complete digestion. The high values for mercury attained decrease the amount of concern for volatilization of the mercury in the sampling and preparation process. Most processed and least processed duplicate samples returned similar values. The procedure for determining water soluble mercury consisted of stirring a 1.0 g sample for 1/2 hour at room temperature with 50 ml of distilled water. The sample was filtered and analyzed for mercury using the procedure outlined above.

Blind duplicates were submitted to the analytical lab in addition to the laboratory's internal duplicates. Duplicate samples were submitted in each batch, and the same sample was submitted in several batches. Lab standards were run and reported, as were blind and lab blanks. Duplicate sample results, standards, and blanks were within acceptable levels.

### 2.3 Water Chemistry

Groundwater samples were taken from six piezometers (Figure 1) on three occasions during the summer. Surface water samples were taken from five fixed sampling sites upstream, downstream and within the tailings twice in the summer and once in the autumn. Surface water and groundwater samples were analyzed for major ions, metals and general chemical analysis. Groundwater samples were filtered before analysis while surface water samples were not. Mercury samples were field preserved. Groundwater mercury samples were filtered before preservation. All analyses were performed at the Environmental Chemistry Laboratory, Victoria General Hospital, Halifax, Nova Scotia.

## 2.4 Biological Sampling

Locations of the 123 biological sampling sites are presented in Figure 1. Each sampling site consisted of a 0.25 $m^2$ quadrat nested in a 4 $m^2$ quadrat. All ground vegetation and shrubs or trees under 50 cm in height were harvested in each 0.25 $cm^2$ quadrat, sorted by species, dried and weighed to the nearest milligram.

Shrub biomass was determined in the 4 $m^2$ quadrats. Direct harvesting of shrub biomass was not feasible because of the large volumes of shrub material present at many of the sampling stations. Instead, shrub biomass was estimated using biomass regression equations which estimate the biomass of a particular shrub from its diameter at 25 cm above-ground. The regression equations for conversion of diameter class measurements to biomass were calculated from specimens collected on site for Alnus rugosa (speckled alder), and Spiraea latifolia (hardhack), and from specimens collected off site for other studies for Acer rubrum (red maple), Prunus pensylvanica (pin-cherry), Lonicera canadensis (American fly-honeysuckle), and Abies balsamea (balsam fir) (7).

For reasons of data availability, and because of similar growth forms, equations derived for one species were sometimes used on others. Acer rubrum (red maple) was used for Amelanchier sp. (shadbush), Prunus pensylvanica (pin-cherry) was used for Prunus virginiana (choke-cherry), and Lonicera canadensis (American fly-honeysuckle) was used for Lonicera villosa (Mountain fly-honeysuckle). All equations are of the form:

$$\ln(\text{biomass}) = a + b(\ln(\text{diameter})). \qquad \text{(eq. 1)}$$

The units are $g/m^2$ and cm respectively.

The following table indicates the species for which the equation was derived, the number of measurements included, the adjusted $r^2$ (the estimated $r^2$ for the population, not the realized $r^2$ of the sample), the a and b values for the general equation (eq. 1), and the species to which the equation was applied.

| source species | n | adj $r^2$ | a | b | used for |
|---|---|---|---|---|---|
| Acer rubrum | 44 | .9826 | 4.05458 | 2.49405 | Acer rubrum<br>Amelanchier spp. |
| Alnus rugosa | 26 | .9897 | 3.55096 | 2.88225 | Alnus rugosa |
| Lonicera canadensis | 28 | .9532 | 4.41473 | 2.25260 | Lonicera villosa<br>Rosa carolina |
| Prunus pensylvanica | 37 | .9904 | 3.89179 | 2.56755 | Prunus virginiana<br>Salix humilis |
| Spiraea latifolia | 27 | .9614 | 4.32309 | 2.41333 | Spiraea latifolia |

Conversion of diameter measurements for Picea glauca (white spruce) was accomplished using equations from Freedman et al. (13).

At each sampling site the diameters of all shrubs within the 4 $m^2$ quadrat were recorded. These diameter measurements were then entered into the regression equations to calculate the weight of each shrub. Shrub weights were, in turn, summed to give the total above-ground shrub biomass for each sampling site.

Additional data collected at each sample site included the depth to the water table, depth of the organic matter layer, the percent organic matter content of the upper 10 cm of the soil and soil bulk density. To determine water table depth a metal pole was used to create a small well approximately 50 cm deep and 2-3 cm wide. The water level in each well was allowed to equilibrate for a minimum of 30 minutes at which time depth to the water table from the soil surface was measured with a metre stick. At most sampling sites, a distinctive brown humus layer was present on top of the grey tailings. The thickness of this organic matter layer was measured from a 10 cm long soil core taken at each sampling station using a modified bulb planter. The percent organic matter content of each core was determined by loss on ignition. Soil bulk density consisted of the dry weight of the 10 cm soil core taken at each sampling site expressed as $kg/m^3$ of soil.

The arsenic and mercury concentrations of the biomass samples were determined by the Mineral Engineering Section of the Technical University of Nova Scotia. The minimum sample size for analysis was 0.5 g. Species which had fewer than 10 samples above this minimum weight were not submitted except for Chara globularis (n=8). Species with more than 30 suitable samples were reduced by 5% (but not to below 30) to keep the total analysis within budget. Samples of 0.5 g were placed in clean, dry 38 x 200 mm test tubes. They were then predigested in 5.0 ml of concentrated $HNO_3$ overnight at room temperature. The digestions then proceeded for two hours at 95°C in a water bath. The samples were then analyzed for arsenic and mercury using the techniques described for the tailings samples.

Alnus rugosa and Spiraea latifolia were partitioned into stem and foliage components in order to determine whether foliage and wood differed in their arsenic and mercury concentrations. Biomass values for these two woody species were based on a combination of plants less than 50 cm tall collected on the site, and estimations based on diameter regressions for plants taller than 50 cm. The regressions were based on plants collected on the tailings area, but not attributable to specific plots, hence these plants were not submitted for analysis. Consequently the number of samples for these two species were lower than their frequency suggested and their values may be biased because all the material submitted for analysis was from small plants.

Some statistical analyses were run separately for the foliage and wood components of Alnus rugosa and Spiraea latifolia. For other purposes a composite for each species was used. This composite was calculated by partitioning the trees in each diameter class into wood and foliage based on resource partitioning equations in Crowell, (7), multiplying by the appropriate concentration and summing the diameter classes.

Only above-ground biomass was available for arsenic and mercury analysis of biomass collected at the sampling site. Whole plant samples collected on the tailings during a preliminary study were used to determine the relationship between concentrations of arsenic and mercury in roots and shoots. The species tested included Equisetum fluviatile (water horsetail), Juncus articulatus (rush), Juncus pelocarpus, Dulichium arundinaceum, and Leersia oryzoides (rice cut-grass). A minimum of five individual plants of each species were collected from various locations in the study area. The plants were carefully washed to remove attached soil particles. Roots were separated from shoots, and the samples were dried, homogenized and sent to the Victoria General Hospital Environmental Chemistry Laboratory in Halifax for arsenic and mercury analysis.

## 3.0 DATA ANALYSIS

All the statistical analyses were run using SPSS/PC+ Version 2.0. The 123 sites were clustered into communities based solely on biomass data using the procedure Cluster. The data were first transformed by taking the log natural of 1 plus the biomass, thus reducing the effect of extreme values and equating absent species to 0. Squared Euclidean distance and the centroid clustering algorithm were specified. Of the 123 sites, 114 were classified into ten communities (leaving nine outliers) based on examination of the cluster diagram.

Two discriminant analyses (principle components method) were performed using these 11 communities. In the first discriminant analysis the biomass data (ln values) were entered to examine the consistency of cluster assignments. The results showed only a small number of misclassifications. In the second discriminant analysis the chemical and physical parameters were used to examine the groups.

A one way analysis of variance was used to examine differences in the various physical variables over the 11 community groups. The Student Newman Keuls multiple range test was used to assess the 55 possible comparisons between groups for each variable to determine which differences were significant. In some cases we present the results as indicators even though we rejected the equality of variance hypothesis.

Regression analysis was used to examine the relationship between the physical variables and the biomass, tissue arsenic and mercury data for each species. Interpretation of the relation between biological and physical data was augmented by examining the correlation between each species and all the physical variables.

Twenty chemical and physical variables were included in most analyses. These were depth to water table, percent soil organic matter content, thickness of the organic matter layer (in a 10 cm core), soil bulk density, weight of the soil sink, float and coarse organic matter fractions, and 12 soil chemistry measurements. These soil chemistry measurements consisted of three values for each of the acid and water leaches for both arsenic and mercury. The three values were from the sink and float fractions and their weight weighted total.

# 4.0 RESULTS AND DISCUSSION

## 4.1 Mineralogy of the Tailings

The predominant mineral constituent of the tailings was vein quartz. Grains of vein quartz commonly have minor included sulphides - usually arsenopyrite but also pyrite and minor pyrrhotite. Chlorite was also an included mineral in the quartz.

The next most common grains in the tailings were rock fragments. These fragments were micaceous (muscovite and chlorite) metasedimentary rocks that host the quartz veins at Oldham. The rock fragments contained sufficient magnetic oxides to make them easily separated by Franz magnetic separator. Only rarely did the rock fragments contain visible sulphides.

The next most common mineral constituents were a suite of iron and titanium oxides including magnetite, titanomagnetite, ilmenite, and rutile. They were found as separate grains but most commonly as inclusions in all other grain types, most abundantly in the rock fragments.

Sulphides were common as well and varied considerably in abundance from sample to sample. By far the dominant sulphide was arsenopyrite. Pyrite and pyrrhotite were subordinant and chalcopyrite was common as small inclusions in pyrite. Trace amounts of galena and sphalerite were also present.

Accessory minerals were very minor. Vein feldspar and vein carbonate (probably calcite but iron and manganese content are common in analyses of other gold district minerals in Nova Scotia) have been identified. Secondary carbonate as hardpan was found in some of the sample sites near the level of the summertime water table.

A few small gold grains were noted but only as inclusions in arsenopyrite with quartz. The quality of polish of the gold grains was not sufficient to estimate the mercury content. (It is difficult to obtain a good polish to soft gold when it occurs in hard brittle arsenopyrite.) No liquid mercury was observed.

Most of the grains were unaltered though a few of the iron oxide grains have thin hematite (oxidized iron oxide; $Fe_2O_3$) rims. Sulphides were typically not altered.

## 4.2 Chemical Analysis of the Tailings

Arsenic and Mercury analyses from the main tailings accumulation at Oldham indicate significant concentrations of both arsenic and mercury. Mean concentration of acid extractable mercury was 5.45 parts per million (ppm) (one standard deviation = 3.66 ppm where n = 131) and mean concentration of acid extractable arsenic was 1900 ppm (one standard deviation = 3200 ppm where n = 131). Mercury values ranged from 1.1 to 19.9 ppm: all values were elevated at least two orders of magnitude from expected background in the surrounding rock that was mined for gold ore. Two bedrock samples analyzed in this study were 0.13 and 0.10 ppm mercury and 450 and 275 ppm arsenic.

Arsenic concentration in the tailings ranged from 25 ppm to 2.4 weight percent (24000 ppm). These extreme values should be expected since the tailings are the waste from a vein quartz - arsenopyrite (FeAsS) - gold concentrate in which everything but gold was waste. The material that was mined was hand separated both underground to reduce haulage and at least once on the surface to decrease millage. Messervey and Goudge (1942 and 1943) provide two annual figures for this from 1941 and 1942 of 54% and 57% hoisted material hand picked to waste. Pieces of quartz with visible gold, arsenopyrite (associated spatially with gold throughout Nova Scotia), slate associated with the quartz veins (especially late in the history of the deposit as the grade milled decreased and tonnages increased), and vein quartz would have constituted the mill feed. In addition a sulphide concentrate was made in the mill for shipping for extraction of gold. Unless this concentrate had a very high assay it was rarely sold (no note of concentrate testing or shipping was found in the Oldham files) and must have eventually gone to the tailings (12).

Fifteen samples from various depths in four samples sites were separated into five size fractions and were analyzed for mercury and arsenic. Most of the arsenic and mercury profiles showed significant increase with decreasing grain size, particulary in the clay-sized fraction. Extreme mercury and arsenic values however tended to be in the coarsest sand-sized fraction. Basal samples tended to be erratic.

Arsenic and Mercury concentrations in dry sandy tailings were enriched in areas of uniform sandy tailings of higher gold value. This represents a primary distribution of these components resulting from mining and disposal geometry. Arsenic distribution and concentration was consistent with being bound mostly in the stable sulphide mineral arsenopyrite. Sand-sized arsenopyrite grains and arsenopyrite inclusions in sand-sized quartz grains were abundant in the tailings. The source of the arsenopyrite was the local rock that was mined and milled with the arsenopyrite as a waste (tailings) product.

It is likely that arsenopyrite-rich mill feed would be coarser ground and that more mercury would have been added to this coarser mill feed. Sulphide minerals, especially sulphides of arsenic, were a detriment to efficient amalgamation for gold. Sulphur and sulphides of arsenic, antimony, and bismuth cause blackening of mercury (sickening) and impede the surface qualities which result in the amalgamation with gold. To compensate lime was added (and sometimes lead to remove sulphur) for the effect is less in alkaline solutions (24). In addition to adding lime, it could be expected that the crushing would be coarser to expose fewer brittle sulphide faces to the amalgam and that more mercury might be added to the stamp mortar and the amalgamation or clean-up barrel.

Unlike the arsenic which was a part of the mill feed, the mercury was introduced into the tailings during the amalgamation process. Through much of the history of the Oldham deposit, amalgamation was the only method of gold extraction. Though undocumented, it appears likely that the amalgamation barrel or clean-up barrel was used on concentrates after other extraction processes were used during the last phases of activity in this century (reports from other districts in Nova Scotia on milling processes in this century are found in Taggart (28), Pryor (24), and Richards and Locke (25). Though amalgamation in many districts of the world used only amalgamation plates on the outside of the mortar, it is documented that in central Nova Scotia at the turn of the century much gold was won by amalgam added with the mill feed in the crushing mortar and gold recovered from inside the mortar (14). This would have resulted in much greater use of Hg in the process and a considerable proportion of that Hg would have been added to the mill feed in liquid form during the primary crushing. This crushing during amalgamation would have aided the process of flouring of the mercury (coating or oxidizing the surfaces of mercury drops to prevent their rejoining and collection by mercury trap or amalgam plate) especially in ores with high clay and mica content (slates) or high sulphide content (arsenopyrite). Both are noted in the descriptions of typical lots of mill feed into the districts only mill by Hardman (14).

Mercury is present in only negligible amounts in the local bedrock. Neither mercury minerals nor liquid mercury were observed in the tailings. Distribution and concentration of mercury is consistent with the mercury residing in the tailings as fine grains or adhered to fine grains in the clay silicate fraction and in the fine-grained organic fraction. This results in mercury enrichment in the soil horizon, buried soil horizons, and basal clay layers or clay substrate. The loss of mercury during the milling process was most likely liquid mercury and particles of mercury amalgamated with gold with the tailings. Inefficient retorting could have added more mercury by air but it is difficult to assess this source. Practice at the time was to retort under water to save mercury and most loss would have been within the retort itself as liquid mercury.

Mercury content of the tailings was high indicating inefficient recovery of mercury. There was an economic reason for this level of mercury loss that was not simply inefficiency. The grades were high in relation to minimum grades of the time. An example is given by Malcolm (18) in the records of production from the Sterling Lead over the period 1904 to 1910. The Sterling data shows an extremely high grade compared to that of other workings in the same district which closely match the range of grades common in other Nova Scotia gold districts. Most of the tonnage developed in the history of the Oldham district was from the Sterling vein and the Dunbrack vein and both were known for their high grades (26) (27). The average annual grade of the district (as reported) was usually considerably greater than one ounce to the ton. Whether the reason for the high grade was inefficient mine planning or the geological nature of the deposit is difficult to assess. It was commonly contended during the working of the gold in southern Nova Scotia that higher cut-off grades were mined than would be demanded by efficient mining, especially during down-turns in the mining cycle (which mirrored the business cycle). On the other hand, Oldham was worked over a long time by many operators and was always known as a high grade district. Rigorous analyses of the economic basis of mining these deposits has not been made in the mining literature of the time nor in the historical analytical record and doing such is beyond the scope of this work. Let the analyses end for now at the observation that high mercury content in tailings required high grade to justify the inefficient use of retorting and at the same time to generate mining long enough to produce a large quantity of tailings.

The high grades at Oldham may also explain both the high gold contents of tailings and the probable late date of the introduction of other extraction technologies at Oldham. The cut-off grade used by Seabright for the tailings was 2 g/tonne which converts to 0.058 oz/t or only 2% of a common grade at Oldham, 2.4 oz/t. A recovery of 98% is efficient.

| | Sterling Lead | | | other workings | | |
|---|---|---|---|---|---|---|
| year | Au | tons | grade | Au | tons | grade |
| 1904 | 498 | 214 | 2.33 | 306 | 338 | 0.91 |
| 1905 | 1146 | 665 | 2.00 | 256 | 522 | 0.49 |
| 1906 | 1249 | 804 | 1.55 | 243 | 590 | 0.41 |
| 1907 | 853 | 362 | 2.36 | 41 | 133 | 0.31 |
| 1908 | 2384 | 526 | 4.53 | 74 | 228 | 0.32 |
| 1909 | 2710 | 940 | 2.88 | 308 | 433 | 0.71 |
| 1910 | 2419 | 881 | 2.75 | 517 | 735 | 0.70 |
| average | 11259 | 4392 | 2.56 | 1745 | 2979 | 0.59 |

Whole rock analyses was performed on the surface samples along a 170 m transect across the tailings to determine the average rock equivalent of the tailings. Results of the analyses of both sink fraction and float fraction were similar when recalculated on a volatile-free basis. The analyses were similar in major element composition, not to quartz vein content which should be at least 90 weight percent $SiO_2$, but are within the range of compositions of Goldenville Formation wackes and intermediate between that of Goldenville Formation slates and vein quartz. This result could only be obtained if the mill feed had a significant proportion of slate with the vein quartz. Both are common fractions within samples as seen in microscope examination.

The impact of crushing considerable tonnages of quartz on mercury loss should have been significant. The sericitic muscovite and the graphitic carbon in the slates at Oldham would have increased coating of the mercury added to the crushing mortar (sickening) resulting in persistence of fine mercury droplets (flouring) and resultant loss of these small mercury droplets to the tailings.

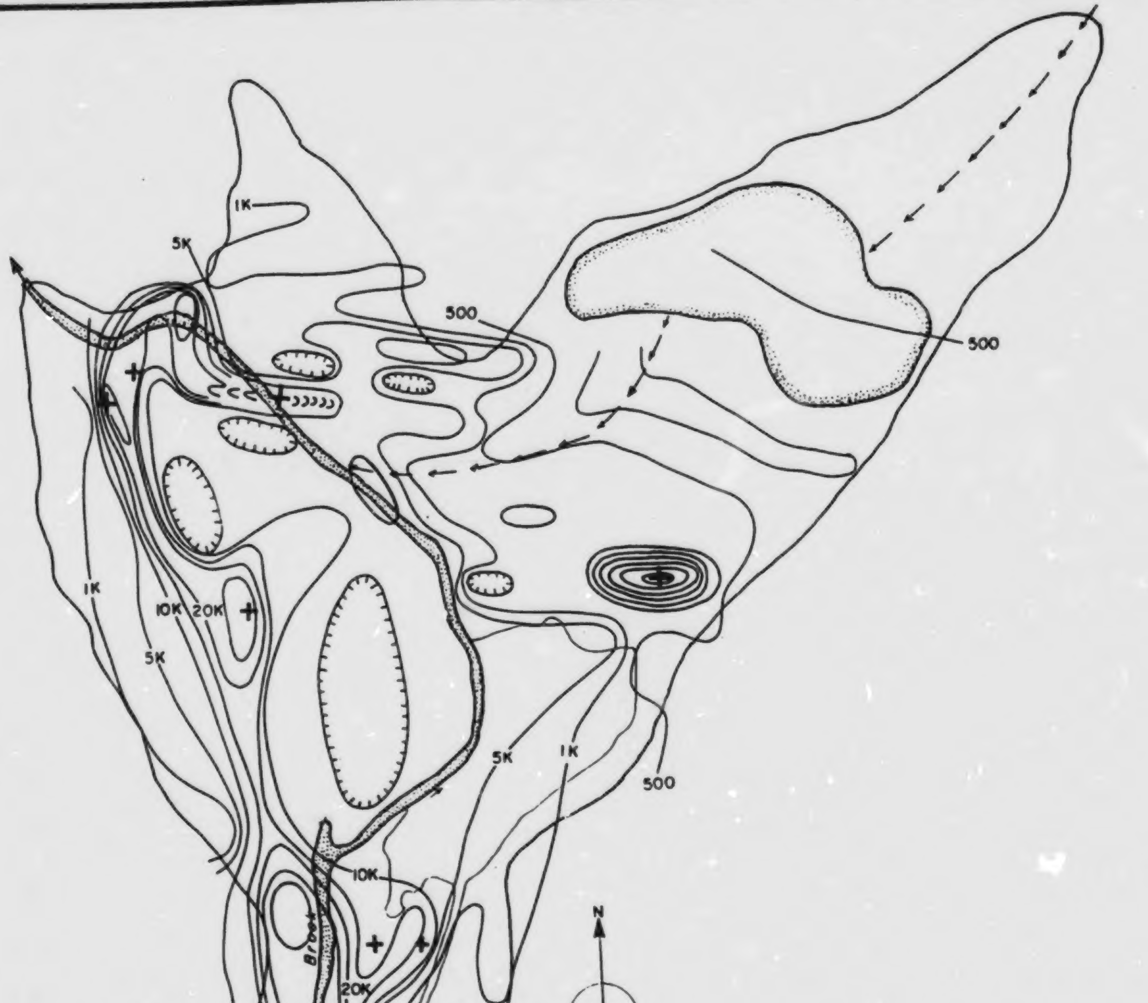
Though the milling history of the deposit is incomplete, study of the historical record allows a fairly complete picture of milling practice at Oldham. Initial work on the deposit was undoubtedly by stamp mill and amalgamation. Several small mills at various sites are noted on the plans of Faribault (9) but the development history indicates that few of these accounted for much tonnage (18). From at least 1885 and probably before the only mill site (occasionally two mills worked on either side of the stream at this site) in the district was at the upstream end of the Oldham #1 tailings deposit (18). A good account of the milling practice by the only mill in the district is given by Hardman (14) for a mill that operated from 1885 to 1894 and by Flynn (12) for a mill that operated from 1934 to 1943. Both were stamp mills varying from 10 to 20 stamps that recovered 80% of the gold that they recovered from amalgamation inside the crushing mortar. Annual mine reports note that the twentieth century mill took delivery of a ball mill but Flynn (12) notes that it was not used because of inefficient recovery of both gold and mercury.

Though production records show that 40% of the tonnage crushed was from 1936 to 1942, amalgamation was used during this lower grade period of mining activity even though the method had been in disuse for at least a generation (12).

The record also explains the profiles of tailings common in the upstream portion of the main deposit which have two deposits separated by a soil layer. With only a few short periods of inactivity, the Oldham district was in relatively continuous production from 1862 until 1910 (18). There was a 25 year period of inactivity with only a few small attempts at mining until the last period of mining between 1936 and 1942 (20). This final period accounts for only 14% of the gold production from the district but for 42% of the tonnage crushed. The tonnage crushed produces tailings so that roughly half of the tailings were produced relatively continuously over the 48 years after first production in 1862 and the second half of the tailings were produced over about 6 years after a 25 year hiatus. This period of inactivity was sufficient to establish a soil at the upstream end of the deposit and presumably some of the alder growth that thrives on this area of the deposit today. This vegetated area would have affected the manner of tailings distribution during this last period of tailings production.

Redistribution of arsenic within the tailings appears less than that of mercury. Erosion of solid tailings particles downstream away from the tailings may be a major factor in the mobility of arsenic. Redistribution of the mercury within the solid tailings was evident. In distal tailings, with lower bulk composition of mercury and arsenic and a finer grain size, mercury was enriched in the upper samples of a profile. In proximal tailings mercury was often depleted in the upper samples. Mechanical redistribution by wind would account for this distribution. This is emphasized by maps of arsenic and mercury concentration in surface samples (Figures 2 - 5 ). For the coarse inorganic fraction, both arsenic and mercury show strong influence of the stream in their distribution while in the fine-grained fraction the distribution is controlled by vegetation barriers perpendicular to the prevailing wind direction (west to east, across the stream course). The role of vegetation density and type appears important as cover to stabilize the tailings from wind erosion and as a trap for stabilizing wind blown tailings.

Sample depth had variable effect on mercury and arsenic concentration. Sample sites in the southern alder-covered part of the tailings often had multiple profiles separated by a soil/organic horizon. This probably represents two different times of tailings addition (The periods of most production were the first ten years 1863-1873, 1876-1879, 1885-1893, and 1908-1910). The northern half of the tailings accumulation had simpler profiles. A typical profile had an organic-rich soil layer at the top 5 to 15 centimeters. Enrichment of mercury was usual in this upper zone and is discussed below. A grain size profile would include a fine-grained organic top typically depleted in arsenic and enriched in mercury relative to lower samples, a grey (quartz) and black (arsenopyrite, oxides, and rock fragments) sand containing most of the arsenic, and underlain by a grey clay with or without organic material (the pre-tailings substrate or soil) with high


1K
5K
500
500
1K
10K
20K
5K
5K
1K
500
10K
20K
500
Brook
Black
200
Access Road
200
500
N
0
50
Scale -- Metres
5K
1K
1K
5K
5K
1K

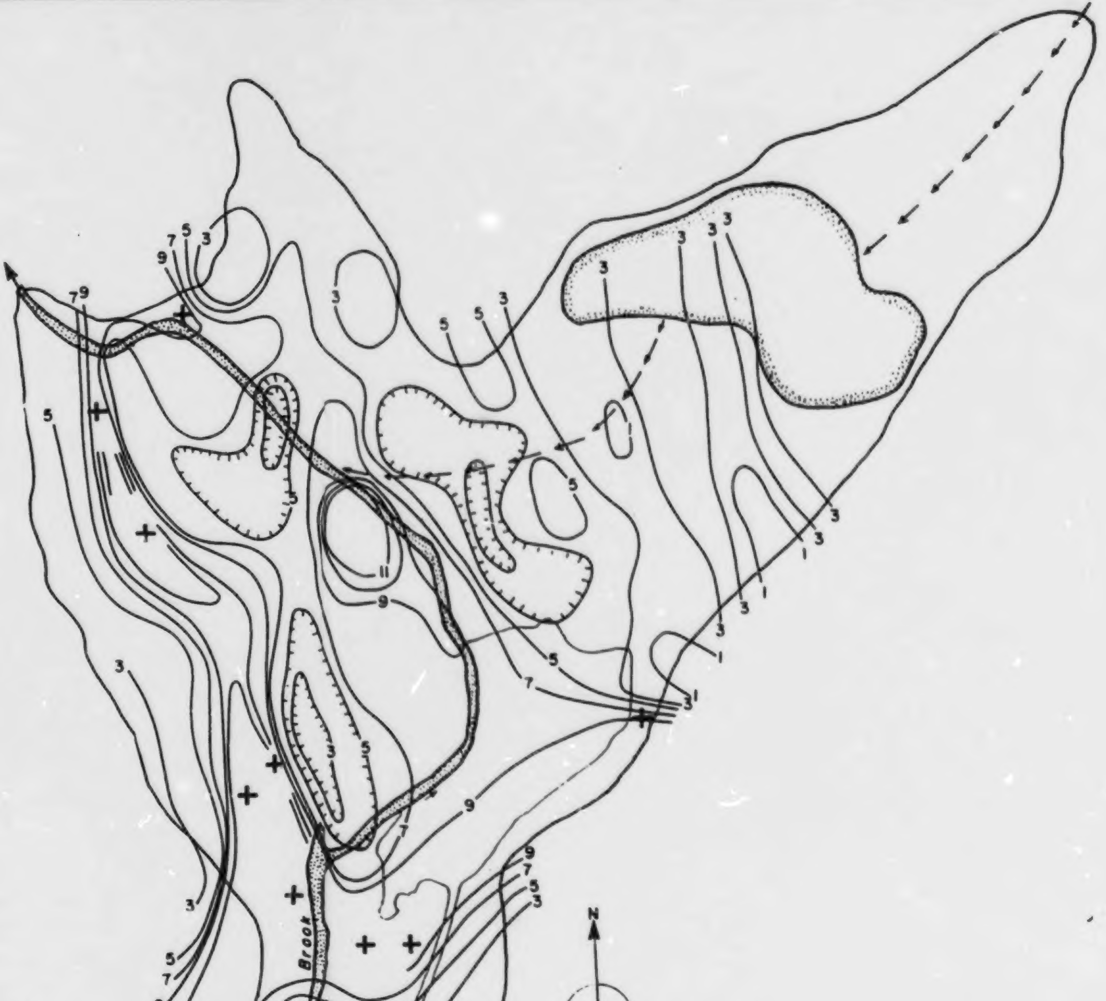
-200- Two hundred parts per million acid extractable Arsenic in the soil float fraction

-10K- Ten thousand parts per million acid extractable Arsenic in the soil float fraction

## OLDHAM TAILINGS:
## CONCENTRATION OF ACID EXTRACTABLE ARSENIC IN THE SOIL FLOAT FRACTION

P. LANE AND ASSOCIATES LIMITED

FIGURE 2


Black Brook
Access Road
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50
Scale -- Metres
-5- Five parts per million acid extractable Arsenic in the soil sink fraction
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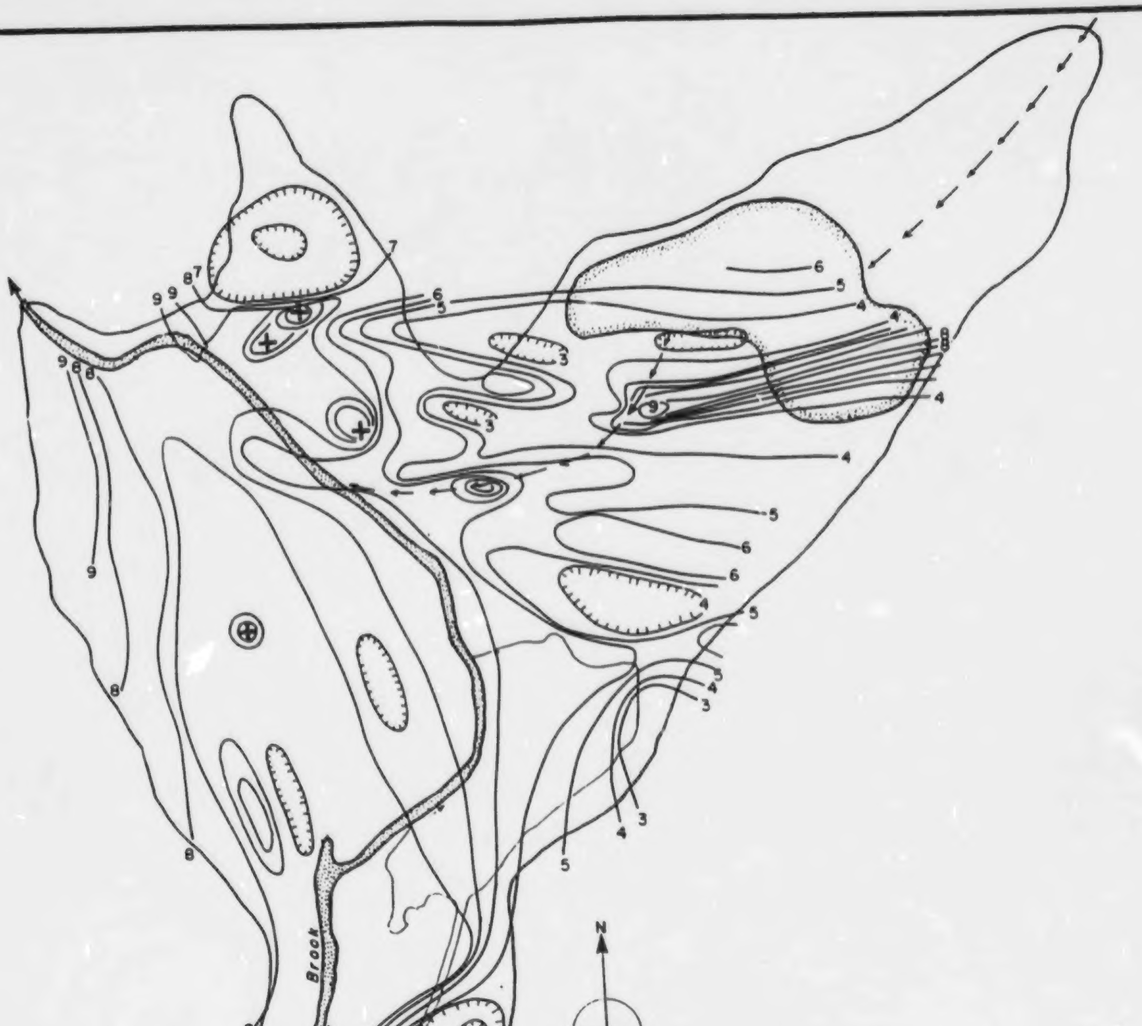
3
5
7
9
11

OLDHAM TAILINGS:
CONCENTRATION OF ACID EXTRACTABLE ARSENIC IN THE SOIL SINK FRACTION

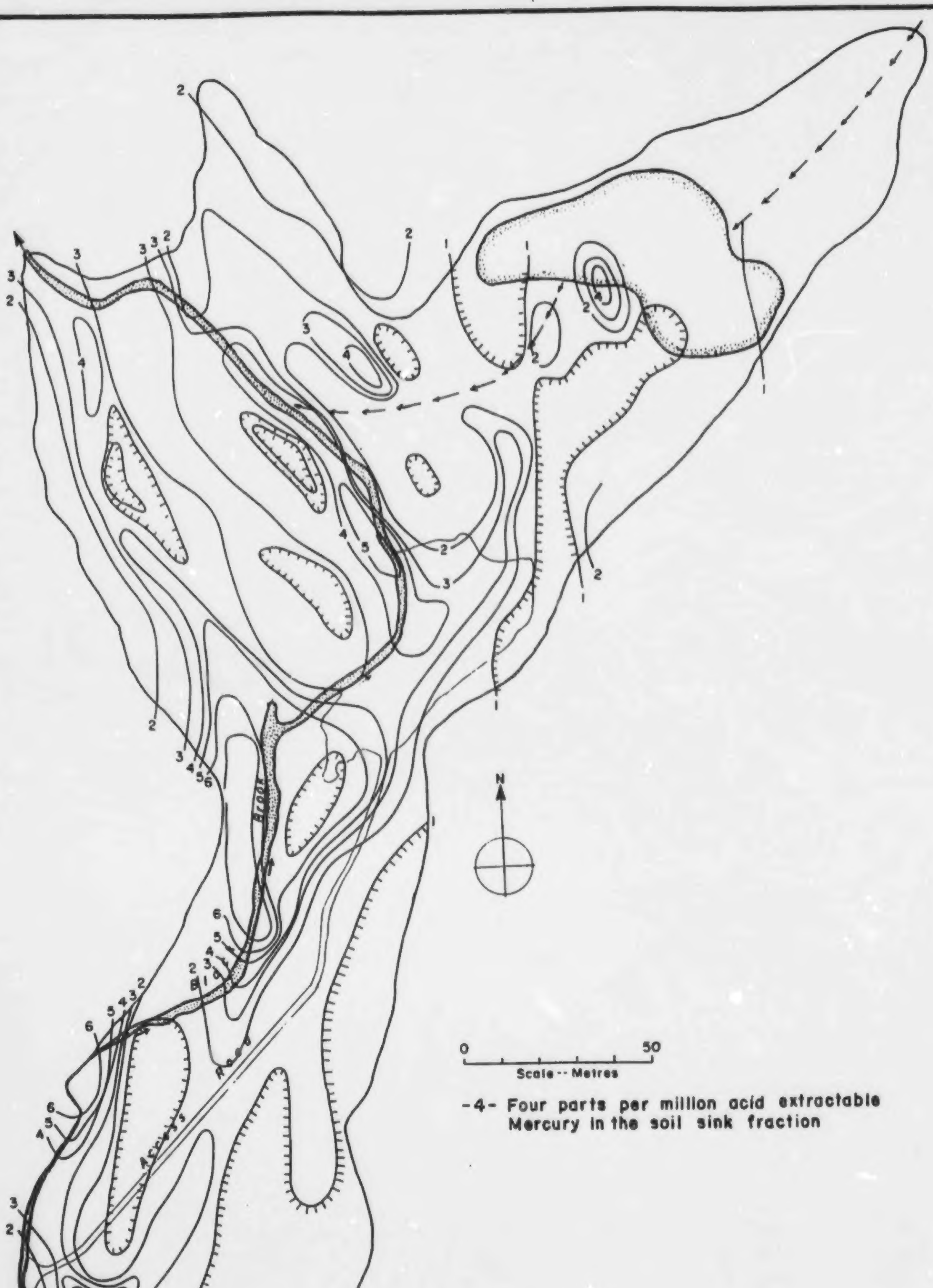
FIGURE 3


N
0
50
Scale -- Metres
-5- Five parts per million acid extractable Mercury in the soil float fraction
Black Brook
Access Road
9 9 8 7
9 8 8
6
5
4
3
2
1
16

OLDHAM TAILINGS:
CONCENTRATION OF ACID EXTRACTABLE MERCURY IN
THE SOIL FLOAT FRACTION

P. LANE AND ASSOCIATES LIMITED

FIGURE 4



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6
Brook
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6
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4
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B
2
3
4
5
6
Road
Access
6
5
4
3
2
N
0
50
Scale -- Metres

-4- Four parts per million acid extractable Mercury in the soil sink fraction

## OLDHAM TAILINGS: CONCENTRATION OF ACID EXTRACTABLE MERCURY IN THE SOIL SINK FRACTION

P. LANE AND ASSOCIATES LIMITED

FIGURE 5

mercury and little arsenic. The distribution of arsenic and mercury within this profile must thus consider grain size.

Lateral distribution of tailings may also be considered in terms of grain size variation. Relatively coarse-grained (medium-grained sand) proximal tailings constituted the ore (in terms of arsenic) to the southwest corner and west margin of the accumulation. Finer-grained and thinner tailings were in the east and north of the accumulation.

The average grain size of each sample was estimated. Higher mercury values were, in general, found in finer grained samples both throughout the tailings accumulation and within any profile. Medium-grained sand samples had mean values of 4.35 ppm mercury (1 standard deviation 3.05 ppm for 51 samples) while silt-sized to clay-sized samples had mean values of 6.22 ppm (1 standard deviation 3.17 ppm for 19 samples). Soil samples with organic material volumetrically important also had higher mercury values: mean of 5.80 ppm (1 standard deviation of 2.44 ppm for 10 samples). Arsenic concentrations in buried tailings tended to be highest in the sand-sized particles (mean 2580 ppm) and lowest in the finer grained samples (fine sands and silts, average 1140 ppm). Arsenic values for clay-sized samples were low with mean values of 620 ppm. Samples from the tailings surface displayed the opposite trend. Sand and silt from the sink fraction contained relatively low concentrations of arsenic (mean 952 ppm). The float fraction containing fine ground particulates and organic matter had an average arsenic concentration of 4890 ppm. This may reflect the effects of weathering. Buried tailings subject to relatively little weathering would contain arsenic as inclusions in the particles. Assuming that only the surfaces of the particles are weathered, fine particles would be expected to contain less arsenic since these particles have a larger surface area to volume ratio than coarse particles. In areas such as the surface of the tailings where weathering is more intense arsenic weathered from the larger particles would be adsorbed by clay particles and organic matter which is plentiful at the surface of the tailings. Over time arsenic would be transferred from the rock fragments to particles having high cation exchange capacity.

The mercury distribution in surface samples was clearly influenced by biotic factors. The more plant cover over tailings the more likely that the mercury levels were elevated. This relationship can be seen by comparing the mercury values in various plant communities or by considering vertical tailings profiles of sample stations. All results in excess of 5 ppm mercury were from samples taken in wet communities with ample plant cover (Figure 1). Mercury enrichment in surface samples was apparently unrelated to the rest of the vertical tailings profile.

These observations can most easily be explained by mechanical trapping of wind-blown mercury-rich fine sediment by plants. Part of the tailings accumulation had little or no plant cover and provided a supply of mercury bound in fine wind-blown particles. Fixing of the entire tailings accumulation would obviously decrease the supply and mobility to wind of fine-grained sediment. Plant cover could also be expected to decrease the supply of the same sediment to stream erosion. This same relationship was not as obvious in the case of arsenic. Either it was less concentrated in the fine fraction of the tailings initially or fine-grained arsenic minerals were more mobile with respect to groundwater than mercury and removed by solution.

The potential toxicity of arsenic in soils is primarily determined by the level of water soluble arsenic which is readily available for uptake by plant root systems (21). Arsenic is readily adsorbed to clay, organic matter and available iron and aluminum oxides in the soil (15) so that water soluble arsenic concentrations decline as these factors increase in the soil. Mercury is similarly adsorbed to organic material (16) (19) and to clay particles (22) in the soil. In this study an average of 7.0± 1.3% of the total soil arsenic and 2.0± 0.2% of the total soil mercury were available as water soluble arsenic and mercury. In surface tailings, the soil float fraction which was composed of clay-sized particles and fine organic matter contained the highest average concentrations of acid extractable arsenic (4890 ppm) and mercury (6.40 ppm) while the soil sink fraction composed primarily of sandy tailings had the lowest concentration of acid extractable arsenic (952 ppm) and mercury (2.18 ppm). The lower concentration in the sink fractions probably represents the results of up to 120 years of weathering of the tailings. The clay fraction and the organic fraction would adsorb arsenic and mercury weathered from both the fine and coarse grained tailings. Artificial leaching of the float fraction of the tailings released an average 6.0± 1.1% of the total arsenic and 2.0± 0.1% of the total mercury. Similar leaching of the soil sink fractions released an average of 17.0± 5.8% of the arsenic and 1.0± 0.1% of the total mercury. These results indicate that mercury is retained by the soil to a higher degree than arsenic and that mercury was bound as tightly to coarse particles as to fine particles and organic matter. The high retention for coarse particles may represent mercury which has analgamated with gold or sulfide minerals in the tailings particles.

### 4.3 Groundwater Chemistry

Table 1 presents groundwater chemistry data for samples from six piezometers located on the study site (Figure 1). The groundwater typically had high concentrations of calcium, which contributed to the high hardness and pH values noted in all samples. The high pH would also increase the mobility of cations, such as arsenic, iron and manganese, all of which exceeded recommended concentrations at all sites and on all sampling dates. Concentrations of copper and zinc were slightly in excess of recommended values for piezometers 1, 2 and 4. Mercury, although highly concentrated in the tailings, was generally not detectable in the tailings groundwater suggesting that it was tightly bound to soil particles and subject to very slow weathering. Mercury in excess of recommended values was found on only one date. High concentrations of other metals were not detected.

Temporal fluctuations in cation and anion concentrations in the groundwater were generally low with the exception of arsenic and iron. Concentrations of both cations were low on June 10 and high on June 24 and August 12. Water table depth data from the piezometers indicated that the former dates corresponded to low water periods. A low water table would permit weathering of tailings which are normally waterlogged for much of the year permitting a flush of arsenic and iron into the tailings groundwater.

Table 1. Water quality data for tailings groundwater at Oldham. Values exceeding recommended concentrations are marked with an asterisk. All values are in mg/L unless otherwise stated. Locations of piezometers (P1-P6) are presented in Figure 1.

| | P1 | | | P2 | | |
|---|---|---|---|---|---|---|
| Date | 10/6/88 | 24/6/88 | 12/8/88 | 10/6/88 | 24/6/88 | 12/8/88 |
| Calcium | 36.0 | 56.0 | 55.0 | 40.0 | 47.0 | 54.0 |
| Magnesium | 3.6 | 5.8 | 4.9 | 2.9 | 2.5 | 2.4 |
| Hardness ($CaCo_3$) | 104.8 | 163.7 | 157.3 | 111.7 | 127.5 | 144.9 |
| Alkalinity ($CaCo_3$) | 57.0 | 82.0 | 130.0 | 120.0 | 150.0 | 143.0 |
| Sulfate | 58.0 | 89.0 | 30.0 | 3.8 | <1.0 | 12.0 |
| Chloride | 3.6 | 3.6 | 2.8 | 3.8 | 3.4 | 2.3 |
| Ortho-Phosphorus (P) | 0.22 | 1.5 | 3.2 | 0.16 | 0.27 | 0.19 |
| Nitrate & Nitrite (N) | 0.10 | <0.05 | <0.05 | 0.05 | <0.05 | <0.05 |
| Ammonia (W) | 0.30 | 0.32 | 0.42 | <0.05 | <0.05 | 0.06 |
| Arsenic | 0.080* | 13.0* | 18.1* | 0.200* | 0.790* | 0.860* |
| Iron | 0.25 | 19.0* | 21.0* | 0.04 | 2.3* | 3.7* |
| Manganese | 1.9* | 2.3* | 2.3* | 1.0* | 2.2* | 2.0* |
| Copper | <0.01 | 0.01* | <0.01 | 0.02* | <0.01 | - |
| Zinc | 0.06* | 0.01 | <0.01 | 0.07* | 0.02 | 0.01 |
| Color (T.C.V) | 12.0 | - | 6.0 | 13.0 | - | 53.0* |
| Conductivity (micromho/cm) | 242.0 | 345.0 | 310.0 | 232.0 | 274.0 | 292.0 |
| pH (unit) | 6.60 | 6.40* | 6.70 | 7.30 | 7.50 | 7.20 |
| Lead-ICP & HGA | <0.05 | <0.002 | <0.002 | <0.05 | <0.002 | <0.002 |
| Aluminum | 0.05 | 0.05 | <0.05 | <0.05 | 0.06 | <0.05 |
| Boron | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Barium | 0.040 | 0.021 | 0.019 | 0.027 | 0.007 | 0.013 |
| Beryllium | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cobalt | 0.02 | <0.01 | - | <0.01 | <0.01 | <0.01 |
| Nickel | 0.02 | <0.02 | <0.02 | 0.03 | 0.02 | 0.02 |
| Antimony | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Selenium | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Tin | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Vanadium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cadmium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Mercury (ppm) | - | <0.05 | <0.05 | - | <0.05 | <0.05 |
| Sodium | - | 2.5 | - | - | 2.5 | - |
| Potassium | - | 0.80 | - | - | 1.4 | - |
| Total Organic Carbon | - | 7.5 | - | - | 3.8 | - |

Table 1. (cont'd.)

| | P3 | | | P4 | | |
|---|---|---|---|---|---|---|
| Date | 10/6/88 | 24/6/88 | 12/8/88 | 10/6/88 | 24/6/88 | 12/8/88 |
| Calcium | 131.0 | 112.0 | 104.0 | 143.0 | 142.0 | 153.0 |
| Magnesium | 2.3 | 2.1 | 1.9 | 2.5 | 2.5 | 2.4 |
| Hardness ($CaCo_3$) | 336.5 | 288.2 | 267.3 | 367.2 | 364.8 | 392.0 |
| Alkalinity ($CaCo_3$) | 370.0 | 300.0 | 273.0 | 390.0 | 370.0 | 370.0 |
| Sulfate | <1.0 | <1.0 | <2.0 | 16.0 | 12.0 | <2.0 |
| Chloride | 3.4 | 3.3 | 2.2 | 2.7 | 3.0 | 3.1 |
| Ortho-Phosphorus (P) | 0.32 | <0.1 | 0.06 | 0.26 | 0.82 | <0.01 |
| Nitrate & Nitrite (N) | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ammonia (W) | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.10 |
| Arsenic | 12.2* | 11.8* | 32.0* | 0.190* | 5.7* | 7.0* |
| Iron | 41.0 | 75.0* | 69.0* | 0.10 | 26.0* | 30.0* |
| Manganese | 6.7* | 3.8* | 3.5* | 3.0* | 3.8* | 3.8* |
| Copper | <0.01 | <0.01 | <0.01 | 0.03* | <0.01 | <0.01 |
| Zinc | 0.01 | 0.02 | 0.01 | 0.01 | <0.01 | 0.01 |
| Color (T.C.V) | 480.0* | - | 280*0 | <10.0 | - | 75.0* |
| Conductivity (micromho/cm) | 732.00 | 626.0 | 553.0 | 767.0 | 745.0 | 832.0 |
| pH (units) | 7.00 | 6.90 | 6.70 | 7.30 | 7.00 | 6.90 |
| Lead-ICP & HGA | <0.05 | <0.002 | <0.002 | <0.05 | <0.002 | <0.002 |
| Aluminum | <0.05 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Boron | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Barium | 0.094 | 0.113 | 0.127 | 0.069 | 0.103 | 0.130 |
| Beryllium | <0.005 | 0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cobalt | <0.01 | <0.01 | - | <0.01 | <0.01 | - |
| Nickel | 0.03 | 0.02 | 0.02 | <0.02 | <0.02 | <0.02 |
| Antimony | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Selenium | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Tin | 0.08 | <0.03 | 0.07 | 0.09 | <0.03 | 0.11 |
| Vanadium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cadmium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Mercury (ppm) | - | <0.05 | 0.13* | - | <0.05 | <0.05 |
| Sodium | - | 3.5 | - | - | 2.5 | - |
| Potassium | - | 7.3 | - | - | 5.5 | - |
| Total Organic Carbon | - | 9.0 | - | - | 5.0 | - |

Table 1. (cont'd.)

| | P5 | | | P6 | | |
|---|---|---|---|---|---|---|
| Date | 10/6/88 | 24/6/88 | 12/8/88 | 10/6/88 | 24/6/88 | 12/8/88 |
| Calcium | 105.0 | 161.0 | 94.0 | 76.0 | 96.0 | 87.0 |
| Magnesium | 3.3 | 5.2 | 3.1 | 2.6 | 2.4 | 2.4 |
| Hardness ($CaCo_3$) | 275.6 | 423.6 | 247.6 | 200.4 | 249.7 | 227.3 |
| Alkalinity ($CaCo_3$) | 300.0 | 470.0 | 303.0 | 200.0 | 230.0 | 217.0 |
| Sulfate | 6.1 | <1.0 | <2.0 | 9.8 | 3.90 | 23.0 |
| Chloride | 3.2 | 2.1 | 5.0 | 2.7 | 4.1 | 2.9 |
| Ortho-Phosphorus (P) | 0.83 | 0.41 | 0.60 | 0.59 | 0.34 | 0.26 |
| Nitrate & Nitrite (N) | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Ammonia (N) | 0.10 | <0.05 | <0.29 | <0.05 | 0.07 | <0.05 |
| Arsenic | 1.7* | 12.5* | 9.6* | 1.1* | 3.4* | 2.9* |
| Iron | 0.15 | 45.0* | 19.0* | 0.07 | 15.0* | 12.0* |
| Manganese | 3.9* | 7.4* | 5.9* | 0.39* | 1.8* | 1.4* |
| Copper | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Zinc | 0.01 | 0.01 | <0.01 | 0.01 | <0.01 | <0.01 |
| Color (T.C.V) | 17.0* | - | 330.0* | 10.0 | - | 10.0 |
| Conductivity (micromho/cm) | 545.00 | 920.0 | 570.0 | 386.0 | 445.0 | 431.0 |
| pH (unit) | 7.20 | 6.80 | 6.80 | 7.20 | 6.90 | 7.10 |
| Lead-ICP & HGA | <0.05 | <0.002 | <0.002 | <0.05 | <0.002 | <0.002 |
| Aluminum | <0.05 | <0.05 | <0.05 | <0.05 | 0.05* | <0.05 |
| Boron | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Barium | 0.065 | 0.107 | 0.081 | 0.037 | 0.030 | 0.031 |
| Beryllium | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cobalt | <0.01 | <0.01 | - | <0.01 | <0.01 | |
| Nickel | <0.02 | <0.02 | 0.02 | <0.02 | <0.02 | <0.02 |
| Antimony | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Selenium | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Tin | 0.06 | <0.03 | 0.05 | 0.06 | <0.03 | 0.04 |
| Vanadium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cadmium | <0.01 | - | <0.01 | <0.01 | <0.01 | <0.01 |
| Mercury (ppm) | - | <0.05 | <0.05 | - | <0.05 | <0.05 |
| Sodium | - | 8.6 | - | - | 3.8 | - |
| Potassium | - | 8.9 | - | - | 2.2 | - |
| Total Organic Carbon | - | 18.2 | - | - | 4.5 | - |

Water table depth was measured for all 123 sampling sites on September 21, 1988. Depth to water table ranged from 70 cm below surface to 38 cm above surface with an average depth of 12 cm below surface. Fluctuations in water table depth were monitored at the six piezometers. Temporal variations in water table depth between June 3 and September 21, 1988, ranged from 54 cm at piezometer 2 to 20 cm at piezometer 5 with an average for all sites of 35 cm (Table 2). Fluctuations in water table depth were often rapid as a result of the high porosity of tailings. Fluctuations of up to 8 cm per day were noted, although the average rate of fluctuation for most of the piezometers was about 3.5 cm per day.

### 4.4 Surface Water Chemistry

Table 3 presents surface water chemistry data for five sampling sites on three occasions. Locations of sampling stations are presented in Figure 1. Data for Site 1 upstream of the tailings on Black Brook indicated an oligotrophic stream subjected to acid stress. The high acidity resulted from acid drainage from exposed slates at the headwaters of Black Brook (Halifax International Airport). Acidic conditions permit the mobilization of metals such as aluminum which were highly elevated at Site 1. Copper and chromium were also elevated at this site. As water from Black Brook passes through the tailings (Sites 2 and 3), pH increases probably as a result of inputs of calcium from tailings groundwater. Data for June 6 indicate that the tailings can significantly alter the pH of Black Brook under certain circumstances. In most instances, however, reductions in pH were much less drastic. Concentrations of aluminum tended to decline somewhat as Black Brook passed through the tailings. Aluminum concentrations remained above recommended values at all Black Brook sampling sites in spite of these reductions.

Arsenic concentrations were below detectable limits at Site 1, but they increased to beyond acceptable concentrations at Sites 2 and 3. Inputs of tailings groundwater enriched with arsenic were probably responsible for the increase in arsenic concentrations in Black Brook. Similar inputs of manganese were also noted. Contributions of arsenic from the tailings were highest in the summer months, particularly when stream water flow rates were low and inputs of tailings groundwater formed a relatively high proportion of the water entering the brook.

A small proportion of the surface water passing through the tailings came from a small stream entering the pond in the eastern portion of the study area. Water chemistry from this stream (Site 4) exhibited no water quality parameters other than colour exceeding recommended values. This stream subsequently passed through a small tailings deposit and entered the pond situated on tailings in the study site. Water in the pond was enriched in arsenic and iron by passage through the upstream tailings and probably through ion exchange with the tailings underlying the pond. Concentrations of these cations exceeded recommended values on all sampling dates with the highest concentrations occurring in late summer when stream flow was low.

These data indicate that the tailings deposits on Black Brook have both positive and negative impacts on stream water quality. The tailings reduce stream water acidity; however, they increase concentrations of arsenic and

Table 2. Fluctuations in water table depth in Oldham tailings.

| | Water Table Depth (cm) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June | | | July | | | August | | | | | | Septemb | |
| Date | 3 | 10 | 24 | 10 | 26 | 27 | 2 | 3 | 9 | 12 | 16 | 17 | 6 | 10 |
| Piezometer 1 | 34 | 20 | 38 | 39 | 2 | 7 | 5 | 10 | 23 | 28 | 23 | 20 | 24 | 31 |
| 2 | 40 | 14 | 50 | 61 | 7 | 11 | 10 | 16 | 35 | 36 | 28 | 26 | 36 | 37 |
| 3 | 30 | 25 | 31 | 40 | 8 | 16 | 15 | 19 | 26 | 25 | 12 | 15 | - | - |
| 4 | 26 | 25 | 34 | 37 | 6 | 6 | 7 | 13 | 24 | 26 | 20 | 21 | 27 | 20 |
| 5 | 13 | -2 | 9 | 11 | -7 | -6 | -6 | -6 | -4 | -1 | -3 | -4 | -3 | -2 |
| 6 | 28 | 13 | 30 | 39 | 1 | 2 | 6 | 9 | 14 | 24 | 11 | 17 | 19 | 25 |

Table 3. Water quality data for surface waters entering and leaving the Oldham tailings deposit. Values exceeding recommended concentrations are marked with an asterisk. All values are in mg/L unless otherwise stated. Locations of sampling sites are presented in Figure 1.

| | Site 1<br>Upstream of Tailings | | | Site 2<br>Midway Through Tailing | | |
|---|---|---|---|---|---|---|
| Date | 3/6/88 | 12/8/88 | 5/11/88 | 3/6/88 | 12/8/88 | 5/11/88 |
| Calcium | 1.7 | 1.9 | | 2.7 | 2.6 | |
| Magnesium | 0.49 | 0.60 | | 0.55 | 0.64 | |
| Hardness ($CaCo_3$) | 6.3 | 7.3 | | 9.0 | 9.0 | |
| Alkalinity ($CaCo_3$) | <1.0 | <1.0 | | 0.90 | <1.0 | |
| Sulfate | 7.3 | <2.0 | | 7.7 | <2.0 | |
| Chloride | 3.2 | 3.3 | | 4.2 | 3.61 | |
| Ortho-Phosphorus (P) | <0.01 | <0.01 | | 0.01 | 0.01 | |
| Nitrate & Nitrite (N) | 0.53 | <0.05 | | 0.16 | <0.05 | |
| Ammonia (N) | 0.44 | 0.18 | | 0.28 | 0.17 | |
| Arsenic | <0.005 | <0.005 | 0.020 | 0.060* | 0.130* | 0.040 |
| Iron | 1.2* | 3.2* | | 0.99* | 3.5* | |
| Manganese | 0.08* | 0.10* | | 0.14* | 0.18* | |
| Copper | 0.01* | <0.01 | | <0.01 | <0.01 | |
| Zinc | 0.01 | 0.01 | | 0.01 | 0.01 | |
| Color (T.C.U) | | 96.0* | 81.0* | | 85.08 | 190.0* |
| Conductivity (micromho/cm) | 55.40 | 54.4 | | 43.9 | 48.2 | |
| pH (units) | 4.30* | 4.30* | | 5.50* | 4.60* | |
| Lead-ICP & HGA | <0.05 | <0.002 | | <0.05 | <0.002 | |
| Aluminum | <0.05 | 0.59* | | 0.37* | 0.58* | |
| Boron | <0.02 | <0.02 | | <0.02 | <0.02 | |
| Barium | <0.005 | 0.005 | | <0.005 | 0.005 | |
| Beryllium | <0.005 | <0.005 | | <0.005 | <0.005 | |
| Chromium | 0.02* | <0.01 | | <0.01 | <0.01 | |
| Cobalt | <0.01 | - | | <0.01 | - | |
| Nickel | <0.02 | <0.02 | | <0.02 | <0.02 | |
| Antimony | <0.05 | <0.05 | | <0.05 | <0.05 | |
| Selenium | <0.1 | <0.1 | | <0.1 | <0.1 | |
| Tin | <0.03 | <0.03 | | <0.03 | <0.03 | |
| Vanadium | <0.01 | <0.01 | | <0.01 | <0.01 | |
| Cadmium | <0.01 | <0.01 | | <0.01 | <0.01 | |
| Mercury (ppm) | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Turbidity (J.T.U.) | 1.8 | - | | 1.8 | - | |
| Acidity | 12.0 | - | | 8.3 | - | |

Table 3. (cont'd.)

| | Site 3<br>Downstream of Tailings | | Site 4<br>Upstream of Pond | | Site 5<br>Pond | |
|---|---|---|---|---|---|---|
| Date | 3/6/88 | 12/8/88 | 5/11/88 | 3/6/88 | 12/8/88 | 5/11/88 |
| Calcium | 3.5 | 2.9 | 8.9 | 14.0 | 7.0 | 15.0 |
| Magnesium | 0.61 | 0.67 | 0.71 | 1.1 | 0.79 | 1.0 |
| Hardness ($CaCo_3$) | 11.2 | 9.9 | 25.2 | 39.4 | 20.7 | 41.7 |
| Alkalinity ($CaCo_3$) | 3.1 | <1.0 | 24.0 | 39.0 | 20.0 | 41.0 |
| Sulfate | 7.3 | <2.0 | 4.2 | <2.0 | 3.0 | <2.0 |
| Chloride | 4.0 | 3.8 | 1.8 | 2.1 | 1.3 | 2.1 |
| Ortho-Phosphorus (P) | 0.02 | 0.01 | <0.01 | 0.01 | 0.02 | 0.03 |
| Nitrate & Nitrite (N) | 0.13 | <0.05 | <0.05 | 0.10 | <0.05 | <0.05 |
| Ammonia (N) | 0.24 | 0.17 | <0.05 | <0.05 | <0.05 | <0.05 |
| Arsenic | 0.070* | 0.150* | 0.020 | 0.040 | 0.060* | 0.100* |
| Iron | 0.98* | 4.7* | 0.09 | 0.06 | 0.64* | 0.93* |
| Manganese | 0.15* | 0.21* | <0.01 | 0.02 | 0.03 | 0.19* |
| Copper | <0.01* | <0.01 | <0.01 | <0.01 | <0.01 | 0.01* |
| Zinc | - | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Color (T.C.U) | 85.0* | 190.0* | 15.0 | 22.0* | 29.0* | 41.0* |
| Conductivity (micromho/cm) | 44.20 | 47.2 | 62.6 | 90.2 | 51.3 | 89.6 |
| pH (units) | 6.30* | 4.70* | 7.40 | 7.20 | 7.60 | 7.30 |
| Lead-ICP & HGA | <0.05 | <0.002 | <0.05 | <0.002 | <0.05 | <0.002 |
| Aluminum | 0.30* | 0.67* | 0.08 | <0.05 | <0.05 | <0.05 |
| Boron | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Barium | 0.005 | 0.006 | <0.005 | 0.006 | <0.005 | <0.005 |
| Beryllium | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 |
| Cobalt | <0.01 | - | - | - | <0.01 | - |
| Nickel | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 |
| Antimony | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Selenium | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Tin | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| Vanadium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Cadmium | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Mercury (ppm) | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 |
| Turbidity (J.T.U) | 1.8 | - | 0.3 | - | 1.4 | - |
| Acidity | 6.7 | - | - | - | - | - |

iron. The net effect is negative since pH remains suboptimal after passage of stream water through the tailings, and concentrations of arsenic and iron are increased to levels harmful to stream biota.

## 4.5 Soil Organic Matter

Soil organic matter content was generally low, averaging 5.7% for all of the sites. The lowest values (0.1%) were found in areas bare of vegetation while the highest values were found in marshy alder thickets (61.5%) and along the banks of Black Brook (36.1%). In both of the latter locations, inputs of organic matter were high and decomposition rates were low. At most sampling sites, soil profiles had an organic mat at the surface in which most of the root systems of the resident plants were located. The thickness of this mat varied widely over the study area, usually displaying a pattern similar to that of organic matter content.

## 4.6 The Biotic Environment

### 4.6.1 Tailings Plant Communities

The tailings deposits at Oldham are well vegetated in comparison to many other tailings areas in Nova Scotia. In most areas vegetation coverage exceeded 100%. Species richness was high in most of the tailings plant communities ranging between 12 and 15 species/m$^2$, which is somewhat higher than the species richness of abandoned pasture and shrub thickets on sandy till in Nova Scotia. Table 4 presents a list of 77 species of plants noted in the study area. Many of the species dominant in the various plant communities described below are commonly found on abandoned mine tailings and are probably metal tolerant genotypes derived from local populations. The most widely distributed species on the tailings (Equisetum fluviatile (water horsetail), E. arvense (field horsetail), E. variegatum (horsetail), Juncus effusus (soft rush), Agrostis palustris (creeping bent-grass) and Centaurea nigra (knapweed) are known to be tolerant of high arsenic concentrations or have been shown to be tolerant of other heavy metals (6) (8) (23). Others, such as Juncus articulatus (rush), Viola cucullata (blue violet) and V. pallens (small white violet), belong to genera in which metal tolerant species have been found. None of the species listed in Table 4 are rare in Nova Scotia.

Table 5 presents a list of species common in at least one of ten plant communities found on the tailings area. The criterion for inclusion in the list was a frequency of occurrence of no less than 30% in at least one of the plant communities. This eliminated species whose presence in a community may be the result of chance rather than that species' ability to survive under the environmental conditions prevalent in the community. The plant communities presented in Table 5 were derived from cluster analysis of the species by biomass matrix of all quadrats sampled during the study. Figure 6 presents a schematic of the cluster diagram. The first split in the diagram separated six sample sites (Cluster 11). This was a relatively poor cluster exhibiting a high degree of heterogeneity in species composition, however, it exhibited several traits which warranted its inclusion as a distinct community. All quadrats within this cluster contained Alnus rugosa which was dominant in most

Table 4. List of species noted during the vegetation survey on the Oldham tailings deposit.

| Binomial | Common name |
|---|---|
| *Abies balsamea* | balsam fir |
| *Acer rubrum* | red maple |
| *Agrostis palustris* | creeping bent-grass |
| *Agrostis perennans* | bentgrass |
| *Agrostis scabra* | tickle-grass |
| *Alnus rugosa* | speckled alder |
| *Amelanchier* sp. | shadbush |
| *Aronia arbutifolia* | red chokeberry |
| *Aster lateriflorus* | calico aster |
| *Aster nemoralis* | bog aster |
| *Aster novi-belgii* | New York aster |
| *Aster umbellatus* | tall white aster |
| *Calamagrostis canadensis* | blue-joint |
| *Campylium stellata* | |
| *Carex brunesscens* | sedge |
| *Carex leptalia* | sedge |
| *Carex nigra* | sedge |
| *Carex rostrata* | sedge |
| *Carex stipata* | sedge |
| *Carex tenera* | sedge |
| *Carex viridula* | sedge |
| *Centaurea nigra* | knapweed |
| *Chamaedaphne calyculata* | leatherleaf |
| *Chara globularis* | |
| *Chrysanthemum leucanthemum* | ox-eye-daisy |
| *Cinna latifolia* | wood-reed |
| *Drosera intermedia* | narrow-leaved sundew |
| *Drosera rotundifolia* | round-leaved sundew |
| *Dryopteris thelypteris* | bog fern |
| *Equisetum arvense* | field horsetail |
| *Equisetum fluviatile* | water horsetail |
| *Equisetum variegatum* | horsetail |
| *Eupatorium perfoliatum* | boneset |
| *Festuca rubra* | red fescue |
| *Fragaria virginiana* | wild strawberry |
| *Glyceria fernaldii* | small manna-grass |
| *Hypericum virginicum* | St. John's wort |
| *Iris versicolor* | blue flag |
| *Juncus articulatus* | rush |
| *Juncus effusus* | soft rush |
| *Juncus pelocarpus* | rush |

Table 4. Continued

| Binomial | Common Name |
|---|---|
| Larix laricina | larch |
| Leontodon autumnalis | fall dandelion |
| Linaria vulgaris | butter-and-eggs |
| Lonicera villosa | mountain fly-honeysuckle |
| Lycopus americanus | water-horehound |
| Lycopus uniflorus | bugle weed |
| Lysimachia terrestris | loosestrife |
| Mentha arvense | field mint |
| Muhlenbergia uniflora | |
| Myosotis sp. | forget-me-not |
| Myrica gale | sweet gale |
| Onoclea sensibilis | sensitive fern |
| Osmunda regalis | royal fern |
| Picea glauca | white spruce |
| Picea rubens | red spruce |
| Plantago major | broad-leaved plantain |
| Polytricum commune | hair-cap moss |
| Prunus virginiana | choke cherry |
| Prunella vulgaris | heal-all |
| Ranunculus repens | creeping buttercup |
| Rhinanthus crista-galli | yellow rattle |
| Rosa carolina | wild rose |
| Rubus hispidus | trailing blackberry |
| Rubus pubescens | dewberry |
| Rubus vermontanus | blackberry |
| Salix humilis | small pussy-willow |
| Scirpus rubrotinctus | bulrush |
| Solidago canadensis | Canada goldenrod |
| Solidago rugosa | rough goldenrod |
| Sphagnum sp. | sphagnum moss |
| Spiranthes cernua | nodding ladies'-tresses |
| Spiraea latifolia | hardhack |
| Thalictrum polygamum | meadow-rue |
| Typha latifolia | broad-leaved cattail |
| Utricularia intermedia | bladderwort |
| Viburnum cassinoides | witherod |
| Viola cucullata | blue violet |
| Viola pallens | small white violet |

Table 5. Mean species biomass and frequency of occurrence for all common species in each of 10 plant communities. Plant community codes are as follows: C.g.-E.f.=*Chara globularis* - *Equisetum fluviatile*, J.a.-E.f.=*Juncus articulatus* - *E. fluviatile*, C.s.-E.f.=*Campylium stellata* - *E. fluviatile*, E.a.-A.p.=*Equisetum arvense* - *Agrostis palustris*, E.f.-A.p.=*E. fluviatile* - *A. palustris*, E.a.-E.f.=*E. arvense* - *E. fluviatile*, Tall A.r.-S.l.=Tall *Alnus rugosa* - *Spiraea latifolia*, Short A.r.-S.l.=Short *A. rugosa* - *S. latifolia*, Wet A.r.-S.l.=Wet *A. rugosa* - *S. latifolia* and A.r.-A.r.=*A. rugosa* - *Acer rubrum*

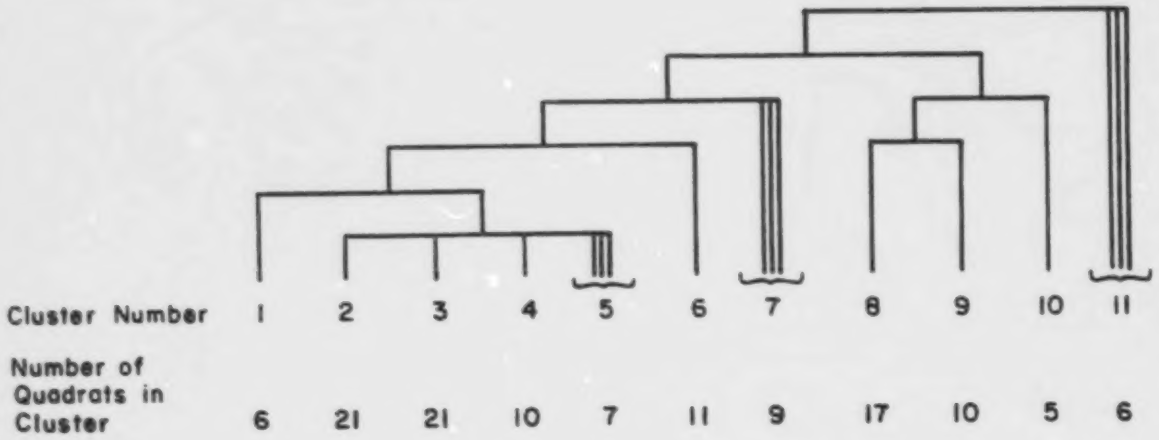
| | Cluster 1<br>Cg-E.f. | | Cluster 2<br>J.a-E.f. | | Cluster 3<br>C.s.-E.f. | | Cluster 4<br>E.f.-A.p. | |
|---|---|---|---|---|---|---|---|---|
| Species | Biomass g/m$^2$ | Frequency (%) | Biomass g/m$^2$ | Frequency (%) | Biomass g/m$^2$ | Frequency (%) | Biomass g/m$^2$ | Frequency (%) |
| *Acer rubrum* | - | - | 1.10 | 10 | - | - | 0.01 | 10 |
| *Agrostis palustris* | - | - | 0.70 | 57 | 16.1 | 100 | 30.5 | 100 |
| *Alnus rugosa* | - | - | 0.75 | 10 | - | - | - | - |
| *Aster novi-belgii* | - | - | 1.04 | 33 | 1.17 | 71 | 9.72 | 70 |
| *Aster umbellatus* | - | - | - | - | - | - | - | - |
| *Campylium stellata* | - | - | - | - | 195 | 95 | 3.23 | 30 |
| *Carex brunessens* | - | - | 0.45 | 10 | - | - | - | - |
| *Carex viridula* | - | - | 0.56 | 33 | 2.04 | 57 | - | - |
| *Centaurea nigra* | - | - | 0.02 | 5 | 3.68 | 43 | 0.40 | 30 |
| *Chara globularis* | 99.6 | 100 | 1.05 | 10 | - | - | - | - |
| *Chrysanthemum leucanthemum* | - | - | 0.01 | 5 | 1.07 | 38 | 0.61 | 20 |
| *Dryopteris thelypteris* | - | - | 1.45 | 14 | 3.09 | 14 | 2.43 | 10 |
| *Equisetum arvense* | - | - | 0.58 | 10 | 0.17 | 10 | 33.2 | 100 |
| *Equisetum fluviatile* | 14.0 | 67 | 35.3 | 100 | 49.3 | 100 | 46.0 | 70 |
| *Equisetum variegatum* | - | - | 0.07 | 5 | 6.54 | 57 | 3.35 | 50 |
| *Equisetum perfoliatum* | - | - | 0.52 | 20 | 1.13 | 52 | 8.10 | 80 |
| *Hypericum virginicum* | - | - | 0.95 | 57 | 0.10 | 19 | 1.08 | 30 |
| *Juncus articulatus* | - | - | 109 | 90 | 2.65 | 48 | 2.13 | 60 |
| *Juncus effusus* | - | - | - | - | - | - | - | - |
| *Larix laricina* | - | - | 0.01 | 5 | 0.02 | 14 | 0.03 | 20 |
| *Leontodon autumnalis* | - | - | 0.01 | 5 | 0.02 | 5 | - | - |
| *Lycopus uniflorus* | - | - | 0.47 | 48 | 0.86 | 67 | 0.55 | 30 |
| *Lysimachia terrestris* | - | - | 1.59 | 62 | 0.54 | 29 | 1.10 | 50 |
| *Onoclea sensibilis* | - | - | 0.25 | 5 | 1.15 | 19 | - | - |
| *Picea glauca* | - | - | - | - | - | - | - | - |
| *Plantago major* | - | - | - | - | 0.01 | 5 | 0.06 | 10 |
| *Polytrichum commune* | - | - | - | - | - | - | - | - |
| *Prunella vulgaris* | - | - | 0.19 | 19 | 2.54 | 67 | 0.41 | 50 |
| *Rubus pubescens* | - | - | - | - | - | - | - | - |
| *Scirpus rubrotinctus* | - | - | - | - | - | - | - | - |
| *Spiraea latifolia* | - | - | 1.43 | 14 | 0.07 | 19 | 1.54 | 60 |
| *Utricularia intermedia* | 8.79 | 100 | 0.05 | 10 | - | - | - | - |
| *Viola cucullata* | - | - | 0.08 | 14 | - | - | 0.49 | 30 |
| *Viola pallens* | - | - | 0.02 | 19 | 0.15 | 38 | 0.82 | 80 |
| Mean Total Biomass | 122 | | 172 | | 296 | | 148 | |

Table 5. Continued

| | Cluster 5<br>E.f.-A.p. | | Cluster 6<br>E.a.-E.f.<br>Tall | | Cluster 8<br>A.r.-S.l.<br>Tall | |
|---|---|---|---|---|---|---|
| Species | Biomass $g/m^2$ | Frequency (%) | Biomass $g/m^2$ | Frequency (%) | Biomass $g/m^2$ | Frequency (%) |
| *Acer rubrum* | 1.78 | 29 | - | - | 0.76 | 29 |
| *Agrostis palustris* | 15.3 | 100 | 20.5 | 91 | 0.17 | 12 |
| *Alnus rugosa* | 1.59 | 14 | - | - | 4790 | 100 |
| *Aster novi-belgii* | 6.50 | 71 | 3.27 | 64 | 0.01 | 6 |
| *Aster umbellatus* | - | - | - | - | 8.39 | 71 |
| *Campylium stellata* | 13.0 | 86 | 35.9 | 45 | 0.42 | 6 |
| *Carex brunessens* | - | - | - | - | - | - |
| *Carex viridula* | 0.02 | 29 | 0.81 | 9 | 6.42 | 24 |
| *Centaurea nigra* | 1.65 | 57 | 0.13 | 9 | 0.26 | 12 |
| *Chara globularis* | - | - | - | - | - | - |
| *Chrysanthemum leucanthemum* | 3.55 | 71 | 1.20 | 36 | - | - |
| *Dryopteris thelypteris* | 0.23 | 14 | 20.1 | 36 | 0.02 | 6 |
| *Equisetum arvense* | 22.5 | 57 | 39.9 | 91 | 7.16 | 71 |
| *Equisetum fluviatile* | 49.5 | 100 | 38.4 | 100 | 1.00 | 59 |
| *Equisetum variegatum* | 9.75 | 71 | 5.92 | 64 | 0.03 | 12 |
| *Eupatorium perfoliatum* | 15.9 | 57 | 20.7 | 73 | - | - |
| *Hypericum virginicum* | - | - | 2.45 | 18 | 0.04 | 12 |
| *Juncus articulatus* | 18.5 | 43 | 6.63 | 55 | 0.02 | 6 |
| *Juncus effusus* | - | - | - | - | 0.07 | 6 |
| *Larix laricina* | 0.01 | 29 | 0.02 | 36 | - | - |
| *Leontodon autumnalis* | - | - | 0.46 | 36 | - | - |
| *Lycopus uniflorus* | 3.18 | 86 | 3.23 | 64 | 0.97 | 41 |
| *Lysimachia terrestris* | 1.59 | 14 | 0.77 | 55 | 0.33 | 24 |
| *Onoclea sensibilis* | 1.60 | 14 | - | - | 4.41 | 47 |
| *Picea glauca* | - | - | 1.63 | 18 | 4.66 | 12 |
| *Plantago major* | 3.94 | 57 | 0.90 | 9 | - | - |
| *Polytrichum commune* | - | - | 19.2 | 27 | - | - |
| *Prunella vulgaris* | 4.54 | 86 | 3.30 | 27 | 0.01 | 6 |
| *Rubus pubescens* | - | - | 0.60 | 9 | 3.76 | 53 |
| *Scirpus rubrotinctus* | - | - | - | - | - | - |
| *Spiraea latifolia* | 2.91 | 57 | 2.98 | 36 | 114 | 94 |
| *Utricularia intermedia* | - | - | - | - | - | - |
| *Viola cucullata* | 0.79 | 29 | 0.52 | 45 | 0.07 | 18 |
| *Viola pallens* | 1.11 | 71 | 1.02 | 55 | 0.10 | 29 |
| Mean Total Biomass | 191 | | 261 | | 5040 | |

Table 5. Continued

| Species | Cluster 9 A.r.-S.l. Short | | Cluster 10 A.r.-S.l. Wet | | Cluster 11 A.r.-A.r. | |
|---|---|---|---|---|---|---|
| | Biomass g/m$^2$ | Frequency (%) | Biomass g/m$_2$ | Frequency (%) | Biomass g/m$^2$ | Frequency (%) |
| *Acer rubrum* | 2.77 | 10 | 9.46 | 40 | 362 | 67 |
| *Agrostis palustris* | 0.17 | 30 | - | - | 10.1 | 67 |
| *Alnus rugosa* | 522 | 100 | 1201 | 100 | 2570 | 100 |
| *Aster novi-belgii* | 3.65 | 40 | 10.2 | 20 | 13.0 | 17 |
| *Aster umbellatus* | 34.8 | 70 | 7.09 | 40 | 9.06 | 67 |
| *Campylium stellata* | 15.6 | 50 | 10.2 | 20 | 20.1 | 50 |
| *Carex brunessens* | 11.3 | 20 | 5.65 | 60 | - | - |
| *Carex viridula* | 0.48 | 20 | 0.23 | 20 | - | - |
| *Centaurea nigra* | - | - | - | - | 0.11 | 17 |
| *Chara globularis* | - | - | - | - | - | - |
| *Chrysanthemum leucanthemum* | - | - | - | - | 0.52 | 17 |
| *Dryopteris thelypteris* | 0.22 | 10 | - | - | - | - |
| *Equisetum arvense* | 6.77 | 60 | - | - | 23.8 | 67 |
| *Equisetum fluviatile* | 9.30 | 70 | 9.34 | 100 | 6.22 | 67 |
| *Equisetum variegatum* | - | - | - | - | 0.04 | 17 |
| *Eupatorium perfoliatum* | 1.50 | 30 | - | - | 6.24 | 50 |
| *Hypericum virginicum* | 0.46 | 60 | 9.86 | 60 | 1.09 | 17 |
| *Juncus articulatus* | 12.6 | 20 | 4.85 | 20 | 2.25 | 17 |
| *Juncus effusus* | 17.5 | 40 | 3.04 | 40 | 0.39 | 17 |
| *Larix laricina* | - | - | - | - | - | - |
| *Leontodon autumnalis* | - | - | - | - | 0.21 | 17 |
| *Lycopus uniflorus* | 0.28 | 30 | 0.66 | 40 | 1.57 | 33 |
| *Lysimachia terrestris* | 4.30 | 60 | 1.00 | 40 | - | - |
| *Onoclea sensibilis* | - | - | 6.15 | 40 | 29.1 | 67 |
| *Picea glauca* | - | - | - | - | 325 | 33 |
| *Plantago major* | - | - | - | - | 0.13 | 17 |
| *Polytrichum commune* | 33.7 | 30 | 10.0 | 40 | 1.39 | 33 |
| *Prunella vulgaris* | - | - | - | - | - | - |
| *Rubus pubescens* | 0.20 | 10 | 0.14 | 20 | 2.05 | 33 |
| *Scirpus rubrotinctus* | 1.45 | 10 | - | - | 8.85 | 50 |
| *Spiraea latifolia* | 115 | 90 | 176 | 80 | 117 | 67 |
| *Utricularia intermedia* | - | - | - | - | - | - |
| *Viola cucullata* | 0.30 | 40 | 0.22 | 20 | 0.55 | 67 |
| *Viola pallens* | 0.38 | 70 | 0.14 | 60 | 0.82 | 67 |
| Mean Total Biomass | 823 | | 1610 | | 3830 | |


Cluster Number
1
2
3
4
5
6
7
8
9
10
11
Number of Quadrats in Cluster
6
21
21
10
7
11
9
17
10
5
6

SCHEMATIC OF CLUSTER DIAGRAM

FIGURE 6

dominant in most of them. Most quadrats also contained trees or shrubs not typically found in other parts of the Oldham tailings. The next split separated shrub dominated communities (Clusters 8,9 and 10) from communities dominated by herbaceous species (Clusters 1-7). Subsequent splits within the shrub communities produced a well-defined cluster (Cluster 8) and two relatively poorly defined clusters (Clusters 9 and 10). These clusters were sufficiently distinct to warrant their inclusion as separate plant communities. Cluster 9 was closely related to Cluster 8 while Cluster 10 was distinct from both 8 and 9. The herbaceous communities were divided into four well-defined groups (Clusters 1-4) and three poorly defined groups (Clusters 5-7). Clusters 5 and 6 were distinct enough to be considered as separate plant communities. Clusters 5 and 7 were composed of sample sites which were distinctive from each other but closely related to the herbaceous sample sites. Sample sites in Cluster 5 were most closely related to the subgroup containing Clusters 2-4. Species compositions of study sites within Cluster 7 were less closely related to those of other study sites within the herbaceous communities but were distinct from the shrub dominated sites, consequently these sites were added to the herbaceous community group immediately after it was separated from the shrub dominated group. Cluster 7 was not considered as a distinct plant community as a result of the lack of similarity between the species composition of the study sites of which it was composed.

Cluster 1 (Table 5, Figure 1) represents a shallow pond plant community dominated by Chara globularis, Equisetum fluviatile and Utricularia intermedia. Species richness was very low in this community (2.6 species/$m^2$) as was total above-ground biomass (122 g/$m^2$). The presence of permanent water appears to be the main determinant of the species composition of this community since Chara globularis and Utricularia intermedia are found only in permanent standing water.

Cluster 2 (Table 5, Figure 1) was composed of quadrats dominated by Juncus articulatus and Equisetum fluviatile. These species accounted for 84% of total above-ground biomass for this community. Other minor species frequently found in this community type were Agrostis palustris, Hypericum virginicum, Lycopus uniflorus and Lysimachia terrestris. Most of the study sites in this community had water tables close to the surface reducing the rate of decomposition of organic material, permitting the build up of a relatively thick organic layer on the soil surface.

In Cluster 3 (Table 5, Figure 1) the dominant species were Campylium stellata and Equisetum fluviatile which made up 83% of total above-ground biomass for this community. Agrostis palustris, Aster novi-belgii, Equisetum variegatum, Prunella vulgaris and Lycopus uniflorus were minor species frequently found in this community.

The species composition of Cluster 4 (Table 5, Figure 1) was dominated by Equisetum arvense, Agrostis palustris and E. fluviatile which together accounted for 74% of the biomass of this community. Other species which were frequently found in this community included Aster novi-belgii, Viola pallens and Eupatorium perfoliatum which accounted for an additional 12% of the community biomass.

Cluster 5 (Table 5, Figure 1) was dominated by *Equisetum fluviatile*, *Agrostis palustris* and *Campylium stellata* which together accounted for only 41% of the total community biomass. Species which occurred frequently but contributed relatively little biomass included *Aster novi-belgii*, *Chrysanthemum lencanthemum*, *Equisetum variegatum*, *Lycopus uniflorus*, *Prunella vulgaris* and *Viola pallens* which accounted for an additional 15% of the community biomass. The relatively low proportion of the total above-ground biomass accounted for by these species may be attributable to the low uniformity in species composition for this community.

The dominant species of Cluster 6 (Table 5, Figure 1) were *Equisetum arvense*, *E. fluviatile* and *Agrostis palustris*. These species accounted for only 38% of the total biomass of this community. *Eupatorium perfoliatum* was the only other species which occurred regularly in this community. It accounted for 8% of the total community biomass. Several species which occurred in the community infrequently accounted for a large proportion (29%) of total community biomass. These speces were *Campylium stellata*, *Polytrichum commune*, and *Dryopteris thelypteris*. This was a poorly defined cluster, therefore, it is not surprising that the species composition of this community was not as uniform as other communities.

The species composition of Cluster 8 (Table 5, Figure 1) was dominated by *Alnus rugosa*, *Spiraea latifolia* and *Aster umbellatus*. Together these species accounted for 97% of the total community biomass. This community was characterized by a mature well-developed *A. rugosa* overstory (hence the name tall *Alnus rugosa* community) with an understory of *S. latifolia* and *A. umbellatus*.

Cluster 9 (Table 5, Figure 1) was termed the short *Alnus rugosa* community since it was characterized by a low shrub canopy dominated by *A. rugosa* and *S. latifolia*. This community had a herbaceous understory which was dominated by a lush growth of *Aster umbellatus*. These species made up 82% of the total community biomass. Small quantities of *Equisetum fluviatile* and *Viola pallens* were frequently encountered in this community. This community appears to represent the tall *Alnus rugosa* community at an earlier stage of succession.

Cluster 10 (Table 5, Figure 1) was dominated by a relatively open canopy of stunted *Alnus rugosa* with an understory of *Spiraea latifolia* and *Equisetum fluviatile*. This community was restricted to swampy areas, hence, the name wet *Alnus rugosa* community. The dominant species of this community accounted for 86% of the total community biomass. No other species occurred regularly in this community.

Cluster 11 (Table 5, Figure 1) was a poor cluster characterized by a highly relativey noncoherant species composition. *Alnus rugosa* was the only species which was common to all of the sampling sites included in this community. It accounted for 67% of the total community biomass. Other species which occurred fairly frequently including *Acer rubrum*, *Agrosits palustris*, *Aster umbellatus*, *Equisetum arvense*, *E. fluviatile*, *Onoclea sensibilis*, *Spiraea latifolia*, *Viola cacullata* and *V. pallens*. Of these species, *Acer rubrum* and *Spiraea latifolia* contributed large quantities of biomass. The herbaceous understory of this community was dominated by *Onoclea sensibilis* and *Equisetum arvense*.

Physical and chemical environment features characteristic of each community are presented in Tables 6 and 7. Differences between communities were detected using one-way analysis of variance and the Student Newman Keuls multiple range test. Matrices of the results of these tests for each physical parameter are presented in Appendix 1. For the sake of brevity and clarity contractions of the full communities titles are used in the following text. These contractions are as follows:

| | |
|---|---|
| Cluster 1 | *Chara globularis* - *Equisetum fluviatile* community becomes the *Chara* community. |
| Cluster 2 | *Juncus articulatus* - *Equisetum fluviatile* community becomes the *Juncus* community |
| Cluster 3 | *Campylium stellata* - *Equisetum fluviatile* community becomes the *Campylium* community |
| Cluster 4 | *Equisetum arvense* - *Agrostis palustris* community remains the same |
| Cluster 5 | *Equisetum fluviatile* - *Agrostis palustris* community remains the same |
| Cluster 6 | *Equisetum arvense* - *Equisetum fluviatile* community remains the same |
| Cluster 7 | not dealt with as a plant community |
| Cluster 8 | Tall *Alnus rugosa* - *Spiraea latifolia* community becomes the tall *Alnus* community |
| Cluster 9 | Short *Alnus rugosa* - *Spiraea latifolia* community becomes the short *Alnus* community |
| Cluster 10 | Wet *Alnus rugosa* - *Spiraea latifolia* community becomes the wet *Alnus* community |
| Cluster 11 | *Alnus rugosa* - *Acer rubrum* community remains the same |

Mean water table depth was highest in the *Chara* community (Cluster 1) and the *Juncus* community (Cluster 2) and was fairly high in the wet *Alnus* community (Cluster 10). Mean water table depths for the remaining communities were very similar ranging between 14 and 20 cm below ground surface. The *Chara* and *Juncus* communities were significantly different from the other communities and each other. No other significant differences were found.

Mean thickness of the organic matter layer was low in the *Chara*, *Campylium*, and *Equisetum fluviatile* - *Agrostis palustris* communities (Clusters 1,3 and 5) was moderate in the *Equisetum arvense* - *Agrostis palustris* and *Equisetum arvense* - *Equisetum fluviatile* communities (Clusters 4 and 6) and high in all of the *Alnus* communities (Clusters 8-11) and the *Juncus*

Table 6. Mean values of soil physical parameters for each of 10 plant communities. Plant community codes are as follows: C.g.-E.f.=*Chara globularis* - *Equisetum fluviatile*, J.a.-E.f.=*Juncus articulatus* - *E. fluviatile*, C.s.-E.f.=*Campylium stellata* - *E. fluviatile*, E.a.-A.p.=*Equisetum arvense* - *Agrostis palustris*, E.f.-A.p.=*E. fluviatile* - *A. palustris*, E.a.-E.f.=*E. arvense* - *E. fluviatile*, Tall A.r.-S.l.=Tall *Alnus rugosa*-*Spiraea latifolia*, Short A.r.-S.l.=Short *A. rugosa* - *S. latifolia*, Wet A.r.-S.l.=Wet *A. rugosa* - *S. latifolia* and A.r.-A.r.=*A. rugosa* - *Acer rubrum*

| | C.g.-E.f. Cluster 1 (n=6) | J.a.-E.f. Cluster 2 (n=21) | C.s.-E.f. Cluster 3 (n=21) | E.a.-A.p. Cluster 4 (n=10) | E.f.-A.p. Cluster 5 (n=7) |
|---|---|---|---|---|---|
| Mean depth of water table [cm (S.D.)] | -35.3(4.23) | -2.71(10.1) | 14.2(7.51) | 19.5(12.9) | 18.7(7.23) |
| Mean thickness of organic layer [cm (S.D.)] | 1.67(0.82) | 5.19(3.39) | 2.05(0.92) | 3.50(2.95) | 2.14(1.22) |
| Mean soil organic matter content [cm (S.D.)] | 4.70(3.77) | 4.66(4.68) | 1.21(0.50) | 6.12(10.0) | 3.67(3.11) |
| Mean Soil bulk density [kg/m$^3$ (S.D.)] | 588(323) | 1046(374) | 1567(541) | 1716(737) | 1795(615) |
| Mean weight of the soil float fraction [kg/m$^3$(S.D.)] | 568(336) | 323(314) | 264(162) | 161(155) | 270(253) |
| Mean weight of the soil sink fraction [kg/m$^3$(S.D.)] | 21.5 (25.4) | 725(454) | 1305(554) | 1557(831) | 1523(697) |
| Mean weight of coarse organic material in the soil [kg/m$^3$(S.D.)] | 1.46(2.70) | 7.96(13.8) | 0.55(1.25) | 0(0) | 1.75(2.59) |

Table 6. continued.

| | E.a.-E.f. Cluster 6 (n=11) | Tall A.r.-S.1 Cluster 8 (n=17) | Short A.r.-S.1. Cluster 9 (n=10) | Wet A.r.-S.1. Cluster 10 (n=5) | A.r.-A.r. Cluster 11 (n=6) |
|---|---|---|---|---|---|
| Mean depth of water table [cm (S.D.)] | 20.3(14.8) | 9.7(13.1) | 14.7(10.6) | 5.20(4.09) | 16.3(9.33) |
| Mean thickness of organic layer [cm (S.D.)] | 4.09(3.05) | 5.76(2.20) | 6.10(2.56) | 8.80(2.68) | 7.00(2.00) |
| Mean soil organic matter content [cm (S.D.)] | 5.86(6.84) | 19.8(17.1) | 24.5(21.1) | 42.6(12.8) | 17.9(16.1) |
| Mean Soil bulk density [kg/m$^3$ (S.D.)] | 1466(619) | 729(443) | 666(690) | 274(65.4) | 741(506) |
| Mean weight of the soil float fraction [kg/m$^3$(S.D.)] | 171(76) | 269(132) | 167(67.7) | 253(62) | 185(69) |
| Mean weight of the soil sink fraction [kg/m$^3$(S.D.)] | 1294(618) | 460(482) | 500(712) | 20.4(18.5) | 556.6(517) |
| Mean weight of coarse organic material in the soil [kg/m$^3$(S.D.)] | 2.77(4.10) | 13.1(10.1) | 5.44(6.55) | 16.9(22.0) | 8.77(6.73) |

Table 7 Mean values for measures of arsenic and mercury in the soil for each of 10 plant communities. Plant community codes are as follows: C.g.-E.f.=*Chara globularis* - *Equisetum fluviatile*, J.a.-E.f.=*Juncus articulatus* - *E. fluviatile*, C.s.-E.f.=*Campylium stellata* - *E. fluviatile*, E.a.-A.p.=*Equisetum arvense* - *Agrostis palustris*, E.f.-A.p.=*E. fluviatile* - *A. palustris*, E.a.-E.f.=*E. arvense* - *E. fluviatile*, Tall A.r.-S.l.=Tall *Alnus rugosa* - *Spiraea latifolia*, Short A.r.-S.l.=Short *A. rugosa* - *S. latifolia*, Wet A.r.-S.l.=Wet *A. rugosa* - *S. latifolia* and A.r.-A.r.=*A. rugosa* - *Acer rubrum*

| | C.g.-E.f. Cluster 1 (n=6) | J.a.-E.f. Cluster 2 (n=20) | C.s.-E.f. Cluster 3 (n=21) | E.a.-A.p. Cluster 4 (n=10) | E.f.-A.p. Cluster 5 (n=7) |
|---|---|---|---|---|---|
| Mean acid extractable As in floating fraction [ppm (S.D.)] | 513(239) | 5500(11340) | 3090(5970) | 8220(9900) | 6920(10290) |
| Mean acid extractable As in sinking fraction [ppm (S.D.)] | 192(55.6)<br>(n=4) | 727(1060) | 387(155) | 1180(1690) | 490(446) |
| Mean total acid extractable As [ppm (S.D.)] | 454(182)<br>(n=4) | 1650(2830) | 746(817) | 3500(7910) | 1040(1100) |
| Mean water soluble As in floating fractions [ppm (S.D.)] | 38.5(29.5) | 137(246) | 80.8(155) | 235(312) | 49.3(58.8) |
| Mean water soluble As in sinking fraction [ppm (S.D.)] | 2.20(1.71)<br>(n=3) | 32.3(46.2) | 23.5(28.0) | 68.4(47.7) | 50.1(59.7) |
| Mean total water soluble As [ppm (S.D.)] | 25.3(12.3) | 41.6(56.5) | 61.4(151) | 92.6(86.8) | 50.1(51.7) |
| Mean acid extractable Hg in floating fraction [ppm (S.D.)] | 5.080(2.04) | 5.73(2.19) | 6.29(3.54) | 8.72(0.95 | 6.69(2.23) |
| Mean acid extractable Hg in sinking fraction [ppm (S.D.)] | 1.76(1.23) | 2.00(1.41) | 1.75(0.845) | 2.54(1.02) | 2.05(1.15) |
| Mean total acid extractable Hg [ppm (S.D.)] | 4.88(2.02) | 3.00(1.39) | 2.48(1.18) | 3.38(1.50) | 2.84(1.27) |
| Mean water soluble Hg in floating fraction [ppm (S.D.)] | 0.066(0.056) | 0.085(0.113) | 0.102(0.052) | 0.126(0.070) | 0.146(0.156 |
| Mean water soluble Hg in sinking fraction [ppm (S.D.)] | 0.011(0.007)<br>(n=3) | 0.009(0.010) | 0.023(0.013) | 0.020(0.015) | 0.030(0.026 |
| Mean total water soluble Hg [ppm (S.D.)] | 0.037(0.022)<br>(n=3) | 0.020(0.017) | 0.042(0.027) | 0.045(0.059) | 0.044(0.039 |

Table 7. continued.

| | E.a.-E.f. Cluster 6 (n=11) | Tall A.r.-S.1 Cluster 8 (n=17) | Short A.r.-S.1. Cluster 9 (n=10) | Wet A.r.-S.1. Cluster 10 (n=5) | A.r.-A.r. Cluster 11 (n=6) |
|---|---|---|---|---|---|
| Mean acid extractable As in floating fraction [ppm (S.D.)] | 7740(6450) | 1390(1800) | 5860(7670) | 2290(3540) | 7410(11460) |
| Mean acid extractable As in sinking fraction [ppm (S.D.)] | 2530(3770) | 608(807) | 293(180) | 224.0(74.4) | 3350(5920) |
| Mean total acid extractable As [ppm (S.D.)] | 3830(4060) | 1190(1620) | 2120(2330) | 2060(3100) | 4550(6420) |
| Mean water soluble As in floating fraction [ppm (S.D.)] | 217(234) | 47.8(99.9) | 50.5(56.7) | 21.8(11.6) | 141(138) |
| Mean water soluble As in sinking fraction [ppm (S.D.)] | 123(214) | 55.2(67.8) | 30.9(48.7) | 19.9(24.2) | 17.0(17.3) |
| Mean total water soluble As [ppm (S.D.)] | 164(215) | 53.3(96.4) | 41.8(47.6) | 19.3(4.76) | 47.4(53.5) |
| Mean acid extractable Hg in floating fraction [ppm (S.D.)] | 9.62(3.52) | 4.91(1.78) | 6.70(4.21) | 2.36(1.03) | 6.32(2.93) |
| Mean acid extractable Hg in sinking fraction [ppm (S.D.)] | 3.29(1.51) | 1.56(1.00) | 2.06(2.08) | 0.87(0.55) | 3.35(3.27) |
| Mean total acid extractable Hg [ppm (S.D.)] | 4.29(2.13) | 3.22(1.82) | 4.25(2.40) | 2.22(0.94) | 4.65(3.06) |
| Mean water soluble Hg in floating fraction [ppm (S.D.)] | 0.217(0.246) | 0.066(0.037) | 0.095(0.127) | 0.008(0.007) | 0.001(0.001) |
| Mean water soluble Hg in sinking fraction [ppm (S.D.)] | .034(0.016) | 0.018(0.012) | 0.030(0.046) | 0.002(0.002) | 0.027(0.016) |
| Mean total water soluble Hg [ppm (S.D.)] | 0.095(0.071) | 0.044(0.024) | 0.069(0.094) | 0.008(0.008) | 0.053(0.037) |

communities (Cluster 2). The low mean value for the Chara, Campylium and Equisetum fluviatile - Agrostis palustris (Clusters 1,3 and 5) communities were significantly lower than values for the Juncus, and all Alnus communities (Clusters 8-11). The wet Alnus community had an organic matter layer which was significantly thicker than the Juncus, Equisetum arvense - Agrostis palustris, Equisetum fluviatile - Agrostis palustris and Equisetum arvense-Equisetum fluviatile communities. Thick organic matter layers would be expected in the Alnus communities since shrubs would contribute large amounts of biomass to the soil each year. The very large value for the wet Alnus community represents both a large input of organic material and a slow rate of decay caused by waterlogged conditions. Similarly, the high value noted for the Juncus community was probably attributable to a slow rate of decay of organic matter. The thin organic matter layer noted for the Chara community was a loose organic mat which was unattached to the inorganic substrate. This organic mat was easily lost during the soil coring operation.

Organic matter content of the soil exhibited a trend similar to that observed for organic matter layer thickness. The lowest values were noted for the herbaceous communities (Clusters 2,3,4,5 and 6) while the highest values were noted for the various Alnus communities (Clusters 8,9,10 and 11). The low organic matter content noted for the Juncus articulatus - Equisetum fluviatile community probably indicates that the large quantity of organic matter associated with this community was composed primarily of only partially decomposed material, which was seived out the sample before loss on ingition was determined. The Alnus rugosa - Acer rubrum community had significantly higher soil organic matter content than the Campylium community which had the lowest value. The tall and short Alnus communities had significantly higher values than all of the herbaceous communities (Clusters 2,3,4,5 and 6), while the wet Alnus community had a higher soil organic matter content than all other communities.

The weight of the floating fraction of the soil sample corresponds to the amount of clay and organic material in the upper 10 cm of the soil. The highest values for this parameter were found in the Chara and Juncus communities (Clusters 1 and 2). Values for the other communities were similar ranging between 161 and 270 $g/m^3$. The weight of the floating fraction for the Chara community was significantly larger than all other communities. This community was established on an exposed clay layer on the bottom of the pond. Clay being much heavier than organic matter would tend to make the weight of the float fraction of this community very large.

The sinking fraction of the soil samples was composed entirely of sand-sized particles found in the upper 10 cm of the soil. The Alnus and Juncus communities (Clusters 2,8,9,10 and 11) had relatively little sand in their soil cores since the upper portion of their soil horizons were occupied by thick mats of accumulated organic matter. The Chara community soil samples also contained relatively little sand since they were underlain by clay. The herbaceous communities characterized by relatively small annual inputs of organic matter (Clusters 3,4,5 and 6) had the largest quantities of sand in their soil samples. These values were significantly larger than those found in the Chara, Juncus and various Alnus communities (Clusters 1,2,8,9,10 and 4).

Coarse organic material was most abundant in the Alnus communities and the Juncus community (Clusters 2,8,9,10 and 11) where organic matter inputs were high and/or decay rates were reduced by the presence of standing water. Dry herbaceous communities (Clusters 3,4,5 and 6) as well as the Chara community (Cluster 1) retained relatively little coarse organic material. The quantities of coarse organic matter found in the tall and wet Alnus communities (Clusters 8 and 10) were significantly larger than those found in the dry herbaceous communities (Clusters 3,4 and 6).

Bulk density measurements integrate the organic, coarse particulate and fine particulate fractions of the soil measured by the previous parameters. Soil bulk density was significantly higher in dry herbaceous communities (Clusters 3,4,5 and 6) than in the Chara, Juncus or the various Alnus communities (Clusters 1,2,8,9,10 and 11). This reflects the large quantities of light organic matter deposited on and incorporated into the tailings underlying these communities. Low bulk density for the Chara community was the result of the inability to extract entire soil cores from this community. Had full cores been available from this community it is likely it would have had the highest soil bulk density since the substrate for the Chara community was almost entirely clay.

Concentrations of acid extractable arsenic in the soil float fraction were low in the Chara, tall Alnus and wet Alnus communities (Clusters 1,8 and 10) and high in the Equisetum arvense - Agrostis palustris, Equisetum arvense - Equisetum fluviatile and Alnus rugosa - Acer rubrum communities (Clusters 4,6 and 11). The differences in the mean values were not significant presumably because of the high variance associated with the means.

Concentrations of acid extractable arsenic in the soil sink fraction displayed a similar trend as the acid extractable arsenic in the float fraction. Low concentrations were found in the Chara, short Alnus and wet Alnus communities. High concentrations were found in the Equisetum arvense-Agrostis palustris, Equisetum arvense - Equisetum fluviatile and Alnus rugosa - Acer rubrum communities (Clusters 4, 6 and 11). The Alnus rugosa - Acer rubrum community had a mean concentration significantly higher than those of the Juncus, Campylium and tall Alnus communities.

Trends for the concentrations of total acid extractable arsenic were very similar to those exhibited by acid extractable arsenic in the soil float fraction except that differences between mean values for various communities were less extreme. No significant differences were found between the communities in spite of the very low concentration noted for the Chara community and the high concentration noted for the Alnus rugosa - Acer rubrum community.

Concentrations of acid extractable mercury in the soil float fraction were high in the Equisetum arvense - Agrostis palustris and Equisetum arvense - Equisetum fluviatile communities (Clusters 4 and 6) and low in the wet Alnus community (Cluster 10). The mean concentration in the Equisetum arvense-Equisetum fluviatile community was significantly higher than concentrations in the Chara, Juncus, Campylium, tall Alnus and wet Alnus communities. The

Equisetum arvense - Equisetum fluviatile community had significantly higher concentrations than the wet and tall Alnus communities. Acid extractable mercury in the float fraction was significantly more highly concentrated in the Campylium community than in the wet Alnus community.

Concentrations of acid extractable mercury in the soil sink fraction varied little between communities with the exception of the wet Alnus community which had a low concentration. One-way analysis of variance indicated significant differences between communities, however, the Student Newman Keuls multiple range test indicated no significant differences between communities.

Concentrations of total acid extractable mercury also varied little between communities. Concentrations were relatively high in the Chara, Alnus rugosa - Acer rubrum, and Equisetum arvense - Equisetum fluviatile communities (Clusters 1,6 and 11) and low in the wet Alnus, Campylium and Equisetum fluviatile - Agrostis palustris communities (Clusters 3,5 and 10). The multiple range test indicated no significant differences between communities, however, significant differences between groups were detected by the one-way analysis of variance.

Mean concentrations of water soluble arsenic in the soil float fraction varied considerably between communities. The lowest concentrations were found in the Chara community as well as the tall, short and wet Alnus communities (Clusters 1,8,9 and 10). The highest concentrations were found in the Equisetum arvense - Agrostis palustris and Equisteum arvense - Equisetum fluviatile communities (Clusters 4 and 6). Differences between the means were not significant as a result of the high variance associated with them.

Mean concentrations of water soluble arsenic in the soil sink fraction also varied considerably between communities. An extremely low mean concentration was noted for the Chara community, however, this difference was not statistically significant as a result of the very low n for this community. The Equisetum arvense - Equisetum fluviatile community had a very high mean concentration of water soluble arsenic in the soil sink fraction. The mean concentration in this community was significantly higher than the mean values for the Juncus and Campylium communities according to the multiple range test. The one-way analysis of variance, however, indicated no significant differences between the communities.

Trends for the mean concentrations of total water soluble arsenic were very similar to those noted for the water soluble arsenic in the soil sink fraction, reflecting the large proportion of the soil mass in most communities composed of sandy tailings. The Equisteum arvense - Equisetum fluviatile community had a very high mean concentration which was significantly higher than the Campylium and tall Alnus communities according to the multiple range test. The one-way analysis of variance detected no significant differences between communities presumably as a result of the high variance associated with their means.

The Equisetum arvense - Equisetum fluviatile community also contained very high concentrations of water soluble mercury in the soil float fraction.

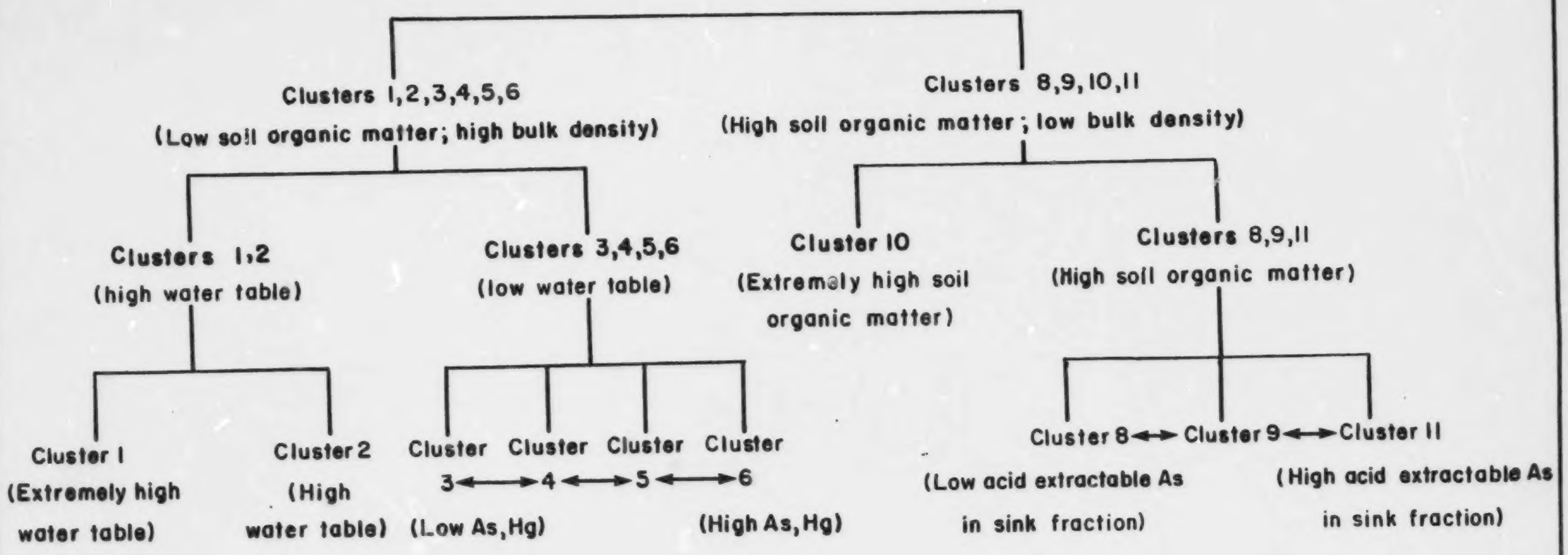
The mean concentration in this community was significantly higher than the means for the Juncus, tall Alnus and wet Alnus communities (Clusters 2,8 and 10). Low concentrations were found in the Chara, tall Alnus, short Alnus and wet Alnus communities (Clusters 1,8,9 and 10).

Mean concentrations of water soluble mercury in the soil sink fraction varied relatively little between communities except for the Chara, Juncus and wet Alnus communities (Clusters 1,2 and 10) which had low concentrations. The soils of these communities are saturated with water and the low concentrations may be attributable to long-term leaching of water soluble mercury from the sandy tailings deposited in these communities. The Juncus community had a significantly lower concentration than the Equisetum arvense - Equisetum fluviatile community.

Trends for the mean concentrations of total water soluble mercury were very similar to those noted for the water soluble mercury in the soil sink fraction, reflecting the fact that sandy tailings contributed most of the mass of the soil samples in most communities. The very high concentration noted for the Equisetum arvense - Equisetum fluviatile community was significantly different from the low concentration in the Juncus community.

The results of the multiple range tests on the physical and chemical site features of the various plant communities can be used to distinguish most plant communities from each other. Figure 7 presents a dendrogram which separates plant communities based on significant differences between physical and chemical features of the communities. The first bifurcation separates herbaceous communities (Clusters 1,2,3,4 and 6) from shrub communities (Clusters 8,9,10 and 11). This split results from significantly higher soil organic matter content and significantly lower soil bulk density in the shrub communities. The herbaceous communities can be further subdivided by differences in water table depths. The Campylium, Equisetum arvense-Agrostis palustris, and Equisetum arvense - Equisetum fluviatile communities (Clusters 3,4 and 6) had water tables significantly lower than the Chara and Juncus communities (Clusters 1 and 2) which were characterized by standing water. The Chara and Juncus communities (Clusters 1 and 2) can be further separated by significant differences in water table depths between them. The Campylium community (Cluster 3) can be distinguished from the Equisetum arvense - Equisetum fluviatile community (Cluster 6) by the significantly higher concentrations of water soluble arsenic and mercury found in the soils on which the latter community was found. The Equisetum fluviatile - Agrostis palustris community (Cluster 4) cannot be distinguished from the Campylium or Equisetum arvense - Equisetum fluviatile communities (Clusters 5 and 6) based on chemical or physical characteristics. It should be noted that this community is floristically very similar to the Campylium and Equisetum arvense - Equisetum fluviatile communities. Subtle differences in species compositions may be accompanied by equally subtle variations in the physical and chemical environments of these communities.

Within the shrub community group (Clusters 8,9,10 and 11), the wet Alnus community (Cluster 10) can be distinguished from the other shrub communities (Clusters 8,9 and 11) by a significantly higher soil organic matter content. The tall Alnus community (Cluster 8) can be distinguished from the Alnus


Clusters 1,2,3,4,5,6
(Low soil organic matter; high bulk density)
Clusters 8,9,10,11
(High soil organic matter; low bulk density)
Clusters 1,2
(high water table)
Clusters 3,4,5,6
(low water table)
Cluster 10
(Extremely high soil organic matter)
Clusters 8,9,11
(High soil organic matter)
Cluster 1
(Extremely high water table)
Cluster 2
(High water table)
Cluster 3
Cluster 4
Cluster 5
Cluster 6
(Low As, Hg)
(High As, Hg)
Cluster 8
Cluster 9
Cluster 11
(Low acid extractable As in sink fraction)
(High acid extractable As in sink fraction)

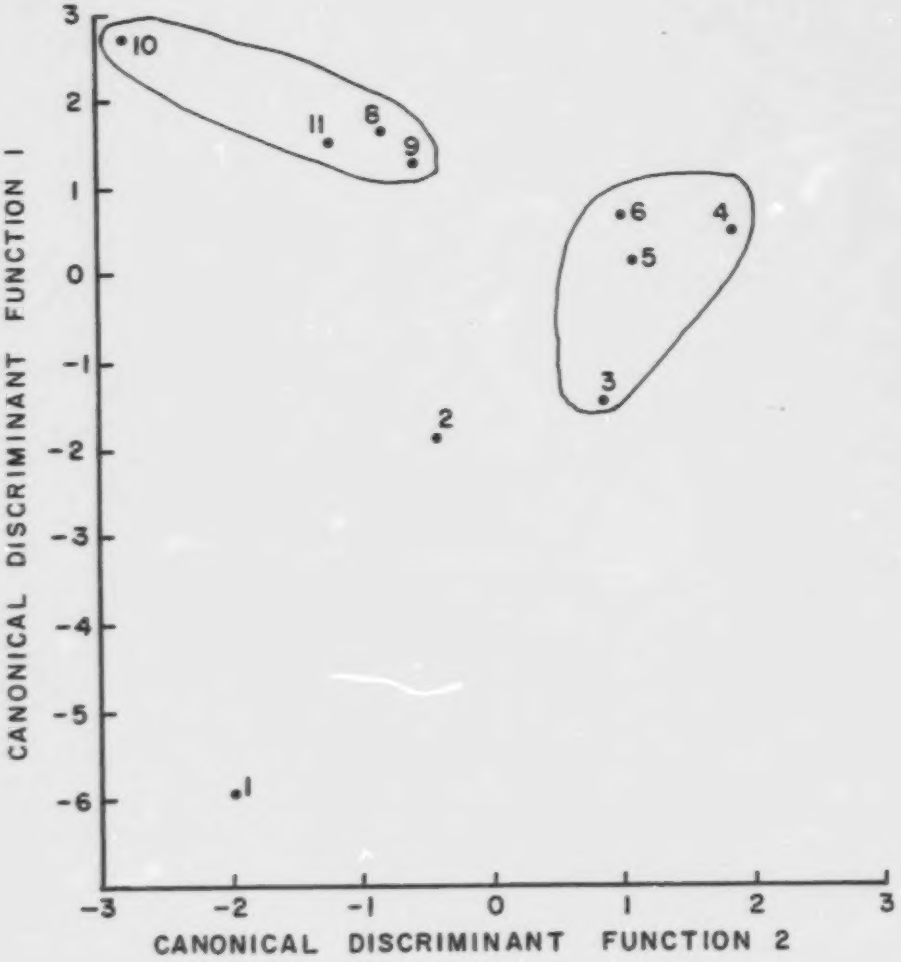
DENDROGRAM SEPARATING PLANT COMMUNITIES BASED ON SIGNIFICANT DIFFERENCES BETWEEN PHYSICAL AND CHEMICAL FEATURES OF THE COMMUNITIES

FIGURE 7

*rugosa* - *Acer rubrum* community (Cluster 11) by the significantly higher acid extractable arsenic concentrations in the soil sink fraction found in the latter community. The short *Alnus* community cannot be distinguished from either the tall *Alnus* community or the *Alnus rugosa* - *Acer rubrum* community. This community is floristically very similar to both the tall *Alnus* and *Alnus rugosa* - *Acer rubrum* communities. Relatively minor variations in physical and chemical conditions in these communities may be responsible for the small differences in species composition.

The relative importance of physical and chemical environmental factors in determining the vegetation composition of the Oldham tailings was determined by a discriminant analysis using these variables as the discriminating variables. The first five discriminant functions explained 48, 21, 10, 6 and 5% of the variance, respectively. The first discriminant function was most highly correlated with depth to water table. The second function was highly positively correlated with weight of the sinking portion of the soil cores and soil bulk density and highly negatively correlated with soil organic matter content (loss on ignition) and thickness of the organic matter layer. All of these parameters describe soil texture. The third discriminant function was most highly correlated with arsenic and mercury concentrations in the soil; most notably, acid extractable mercury in the sink fraction of the soil, total acid extracable arsenic and water soluble arsenic in the floating fraction. The fourth function was most highly correlated with the weight of coarse organic material retained by a number 4 sieve. The fifth function appeared to be related to soil mercury concentrations. The highest correlations were noted for total water soluble mercury, water soluble mercury in the sink fractions, total acid extractable mercury, acid extractable mercury in the floating fraction and the acid extractable mercury in the sinking fraction. These results suggest that soil moisture and texture are the most important factors determining the distribution of plant communities on the tailings while arsenic and mercury concentrations appear to be of secondary importance. These results correspond quite well to the results of the multiple range tests for community physical and chemical attributes.

A plot of community cores for the first two discriminant functions is presented in Figure 8. Dry herbaceous communities (Clusters 3-6) tended to cluster together as did the shrub communities (Clusters 8-11). Within the herbaceous group, the *Campylium* community (Cluster 3) was separated from the other communities. The group centroid for the wet *Alnus* community (Cluster 10) was distinct from the values for the drier shrub communities. The *Chara* and *Juncus* communities (Clusters 1 and 2) were separated from all of the other communities. These results suggest that herbaceous and shrub communities as well as the *Chara* and *Juncus* communities can be readily distinguished from each other based on their scores on the first two discriminant functions which are highly correlated with soil water table depth and soil texture. Within the shrub communities, the wet *Alnus* community can be separated from the other *Alnus* communities and the *Campylium* community can be separated from the other herbaceous communities using these two discriminant functions. These results are very similar to those derived from the community analysis using multiple range tests.



SCATTERPLOT OF COMMUNITY LOCATION ON THE FIRST TWO DISCRIMINANT FUNCTION AXES, USING FEATURES OF THE PHYSICAL ENVIRONMENT AS THE DISCRIMINATING VARIABLES

Although high concentrations of arsenic and mercury were present in the tailings, variations in their concentrations had little effect on plant community distributions. Adsorption of arsenic and mercury to clay and organic matter particles is an important factor in determining the concentrations of these elements which would be available to plants (4) (15) (16) (19) (22). Artificial leaching of the tailings in this study released only 7% of the total acid-extractable arsenic and 2% of the total acid-extractable mercury. The concentrations of arsenic released, however, were on average about eight times higher than concentrations of water-soluble arsenic reported to produce toxic effects in various crop plants (21). Water-soluble mercury concentrations from this study were within the range of water-soluble mercury concentrations which produced toxic effects in plants (22). These results suggest that factors in addition to retention of arsenic and mercury in the soil must come into play in order to explain why arsenic and mercury had little effect on the distribution of plant communities on the tailings.

The chemical nature of the tailings and the tailings groundwater can ameliorate the toxic effects of these metals on the vegetation, weakening the relationship between metal concentration and species composition. High concentrations of calcium have been shown to inhibit the uptake of a number of heavy metals through its effect on cell permeability (2). High concentrations of non-toxic cations may also reduce metal toxicity by reducing the net concentrations of toxic ions in solution, or they may interfere with uptake mechanisms by competing for entry sites. The relatively high concentrations of calcium in the Oldham tailings groundwater may reduce the toxic effects of arsenic and mercury in the vegetation.

Another important factor which may affect the relationship between soil arsenic concentrations and plant community distribution may be the tolerance of the species found on the tailings to these elements. Evidence which will be presented later suggests that most of the common species found on the Oldham tailings are genotypes tolerant of most of the arsenic and mercury concentrations found in the tailings. Although species tended to have preferred ranges of soil arsenic and mercury concentrations in which they were most frequently found, these ranges tended to overlap more than their preferred ranges of soil texture and moisture status; consequently, these factors were more important in determining the distribution of species.

Time is another factor determining the distribution of plant communities on the Oldham tailings. Mine records show that tailings production ceased for a period of 25 years between 1910 and 1936. Forty-two percent of the total tailings produced by the Oldham mill were produced after 1936. This break in tailings production appears to correspond to the presence of buried soil horizons in some portions of the shrub communities in the southern section of the tailings deposit suggesting that vegetation had become established during this period. Buried soil horizons were not found under the herbaceous plant communities. This evidence may indicate that most of the southern portion of the tailings area had been filled with tailings before the northern area was filled. Early establishment of vegetation in the southern portion of the site would establish a biofeedback loop in which the growth of plants provides soil organic matter which improves the nutrient and water status of the tailings and helps to reduce heavy metal toxicity which in turn improves plant and helps to reduce heavy metal toxicity which in turn improves plant productivity which further increases the input of organic matter. Species composition would change as soil conditions were ameliorated since species characteristic of less rigorous environments would be able to survive. The large differences in soil organic matter content between herbaceous and shrub communities probably represents differences in the duration of vegetation cover on the sites where these community types are found. The differences in vegetation on the herbaceous and shrub communities can be thought of as different stages in primary succession from bare tailings to forest. It is likely that several successional sequences are proceeding simultaneously on the tailings since wet areas are likely to follow a successional path somewhat different from dry areas. Successional paths may also be altered by the occurrence of high concentrations of arsenic and mercury in the soil as are found in the *Equisetum arvense* - *Agrostis palustris* and *E. arvense* - *Equisetum fluviatile* communities.

On dry sites the tailings would probably be initially colonized by *Equisetum fluviatile*, *E. arvense* and *Agrostis palustris* which are typically found as colonizers of bare tailings at Oldham. Once small quantities of organic matter had built up *Campylium stellata* would become one of the dominant species. As organic matter continued to build up shrubs such as *Spiraea latifolia* and *Alnus rugosa* would become established. Evidence from existing tailings plant communities suggest that *S. latifolia* would initially be the dominant species, however, it would quickly be supplanted by *A. rugosa* which is capable of producing much more biomass and provides it own nitrogen source through nitrogen fixation. Eventually trees such as *Acer rubrum* would become established as soil conditions were further ameliorated by the large organic matter and nitrogen inputs assoicated with the shrub communities.

On wet sites *Equisetum fluviatile* would probably be the initial colonizer followed by *Juncus articulatus*. *J. articulatus* would become dominant as layers of organic matter built up on top of the tailings. Other species such as *Lysimachia terrestris* and *Hypericum virginicum* would also become abundant at this time. Eventually shrubs tolerant of wet conditions such as *Spiraea latifolia* and *Alnus rugosa* would become established and replace *J. articulatus* as the dominant species. *A. rugosa* may remain the dominant species for many years or it may be replaced by *Acer rubrum* and possibly *Larix laricina*.

In recent years increased utilization of the tailings deposits by humans has resulted in severe disturbance to the herbaceous plant communites. The bare areas noted in Figure 1 were probably caused by trampling damage. This has led to alterations of species composition in a number of areas and may slow or alter the course of succession. We attempted to eliminate this factor in our community descriptions by avoiding areas which had obviously been disturbed.

### 4.6.2 Species Habitat Preferences

The coupling of biological, physical and chemical parameters at each sampling site permitted the assessment of the habitat preferences for common species on the Oldham tailings. This information is useful in selecting plant material for revegetation of disturbed or newly formed tailings deposits. Thirty-three of the seventy-seven species found on the tailings were found frequently enough (found on a minimum of 10 sampling sites) to permit quantification of the physical and chemical environments in which they grew. The parameters most useful in describing the preferred environments of each of the selected species included: depth to water table, thickness of the soil organic matter layer, soil organic matter content (loss on ignition), soil bulk density, and the concentrations of total acid-extractable and water soluble arsenic and mercury in the soil. These data were accumulated for the sites at which each of the selected species was found. The means and ranges for the various parameters are presented in Tables 8 - 10. Correlation analysis was also used to determine habitat preferences for various species. These correlations are presented in Table 11. Only correlations significant at the 0.05 level of significance are presented.

Data regarding arsenic and mercury tolerance and accumulation for each species are also presented. Tolerance to these elements can be implied by looking at the mean and range of soil arsenic and mercury concentrations over which each species was found. The presence of a species over the entire range of soil arsenic and mercury concentrations (particularly water-soluble concentrations) would suggest that it is tolerant of these elements. Restriction of a species to the low end of the concentration range would indicate that it is probably not tolerant of high concentrations of these elements.

The ability of species to accumulate arsenic and mercury was determined by comparing the ranges and averages of arsenic and mercury concentrations in the tissues of each of the selected species. These data are presented in Table 12. The ability of a species to accumulate arsenic from the soil in which it grew was determined by dividing the concentration of arsenic or mercury in the above-ground tissues of a plant found in a particular site by the concentration of total water-soluble arsenic or mercury in the soil at that site. This was termed the arsenic or mercury accumulation index. The mean and ranges of these indices for each species are presented in Table 13.

Correlations between plant tissue arsenic and mercury concentrations, and soil arsenic and mercury concentrations were also used to help evaluate the ability of plants to accumulate these elements. The results of these analyses are presented in Table 14.

In the following text the habitat preferences and arsenic and mercury accumulation ability of each of 33 plant species are presented. For the sake of brevity and clarity, significant correlations between biomass and physical and chemical environmental parameters and between tissue arsenic and mercury concentrations and soil arsenic and mercury concentrations are presented in point form before the body of text for each species.

### Agrostis palustris (creeping bent-grass)

Biomass: positively correlated with weight of the soil sink fraction, soil bulk density, and concentration of total water-soluble arsenic.

Table 8. Soil physical features characteristic of the sites at which each of 33 species were found.

| | | Depth to Water Table (cm) | | Thickness of the Soil Organic Matter Layer (cm) | |
|---|---|---|---|---|---|
| Species | n | mean (SD) | range | mean (SD) | range |
| Maximum Range | | | -38-70 | | 0-10 |
| *Agrostis palustris* | 72 | 14.0 (10.9) | -7-36 | 3.65(2.69) | 1-10 |
| *Alnus rugosa* | 42 | 14.2 (11.9) | 0-41 | 6.14(2.55) | 1-10 |
| *Aster lateriflorus* | 13 | 21.5 (11.5) | 0-41 | 3.85(2.44) | 1- 8 |
| *Aster novi-belgii* | 53 | 15.1 (11.0) | -7-36 | 3.32(2.26) | 1-10 |
| *Aster umbellatus* | 29 | 19.1 (14.3) | 0-70 | 5.62(1.99) | 1-10 |
| *Campylium stellata* | 50 | 17.2 (8.80) | 0-34 | 3.18(2.15) | 1-10 |
| *Carex brunessens* | 9 | 2.56 (4.98) | -6-10 | 6.11(3.22) | 1-10 |
| *Carex viridula* | 32 | 10.8 (11.1) | -7-34 | 3.63(2.92) | 0-10 |
| *Centaurea nigra* | 22 | 16.9 (9.30) | 1-36 | 3.05(1.99) | 1- 7 |
| *Chara globularis* | 8 | -28.5 (13.2) | -38- 6 | 2.00(1.07) | 0- 4 |
| *Chrysanthemum leucanthemum* | 21 | 20.4 (5.98) | 10-33 | 2.67(1.20) | 1- 5 |
| *Dryopteris thelypteris* | 16 | 17.6 (15.7) | -6-51 | 4.19(2.46) | 1-10 |
| *Equisetum arvense* | 53 | 17.5 (12.7) | -16-51 | 4.81(2.80) | 1-10 |
| *Equisetum fluviatile* | 105 | 9.60(15.6) | -38-51 | 4.50(3.14) | 0-10 |
| *Equisetum variegatum* | 33 | 17.9 (9.18) | 3-36 | 3.00(2.46) | 1-10 |
| *Eupatorium perfoliatum* | 46 | 12.5 (10.3) | -7-34 | 4.15(3.02) | 1-10 |
| *Hypericum virginicum* | 38 | 4.50 (8.21) | -10-28 | 6.95(3.14) | 1-10 |
| *Iris versicolor* | 9 | 6.78(14.1) | -7-32 | 5.89(2.80) | 2-10 |
| *Juncus articulatus* | 53 | 4.72(10.0) | -23-28 | 5.15(3.35) | 0-10 |
| *Juncus effusus* | 11 | 11.0 (4.86) | 1-18 | 7.82(2.23) | 4-10 |
| *Lycopus uniflorus* | 64 | 13.5 (11.9) | -10-41 | 4.59(2.75) | 1-10 |
| *Lysimachia terrestris* | 47 | 9.43(11.0) | -7-41 | 5.57(3.27) | 1-10 |
| *Onoclea sensibilis* | 21 | 17.2 (15.7) | 0-70 | 5.38(2.60) | 1-10 |
| *Osmunda regalis* | 8 | 24.0 (25.3) | 1-70 | 3.50(1.20) | 2- 5 |
| *Polytrichum commune* | 12 | 18.3 (10.3) | 1-34 | 4.83(2.37) | 2-10 |
| *Prunella vulgaris* | 36 | 18.4 (8.72) | -7-36 | 2.92(2.02) | 1-10 |
| *Rubus pubescens* | 15 | 19.7 (11.9) | 0-41 | 5.80(2.37) | 1-10 |
| *Solidago canadensis* | 10 | 11.2 (11.8) | -7-31 | 5.50(2.68) | 2-10 |
| *Solidago rugosa* | 6 | 18.7 (13.4) | | 6.17(2.32) | |
| *Spiraea latifolia* | 55 | 17.6 (14.2) | 0-70 | 5.20(2.86) | 1-10 |
| *Thalictrum polygamum* | 23 | 11.3 (10.6) | -7-32 | 4.74(2.42) | 1-10 |
| *Viola pallens* | 55 | 14.2 (10.2) | -7-34 | 4.60(2.84) | 1-10 |

Table 8. continued.

| Species | Soil Organic Matter Content (%) mean (SD) | range | Soil Bulk Density kg/m3 mean (SD) | range |
|---|---|---|---|---|
| Maximum Range | | 0.30-61.5 | | 139-2825 |
| *Agrostis palustris* | 4.57 (6.78) | 0.30-37.8 | 1442(611) | 139-2825 |
| *Alnus rugosa* | 21.8 (18.8) | 0.60-61.5 | 713(525) | 152-2218 |
| *Aster lateriflorus* | 4.17 (3.71) | 0.60-15.3 | 1438(521) | 494-2081 |
| *Aster novi-belgii* | 4.86 (8.93) | 0.30-49.5 | 1426(604) | 212-2676 |
| *Aster umbellatus* | 20.1 (16.6) | 0.60-57.2 | 678(455) | 163-1787 |
| *Campylium stellata* | 7.44(14.3) | 0.30-61.5 | 1403(674) | 163-2825 |
| *Carex brunessens* | 20.8 (21.2) | 0.60-61.5 | 694(596) | 204-1787 |
| *Carex viridula* | 8.06(15.7) | 0.50-57.2 | 1187(568) | 163-2320 |
| *Centaurea nigra* | 6.35(11.2) | 0.70-44.7 | 1285(623) | 265-2594 |
| *Chara globularis* | 4.08 (3.40) | 1.10-10.9 | 698(353) | 199-1207 |
| *Chrysanthemum leucanthemum* | 2.55 (2.29) | 0.50-10.6 | 1607(431) | 811-2331 |
| *Dryopteris thelypteris* | 9.32 (14.4) | 1.20-49.7 | 1144(556) | 165-2018 |
| *Equisetum arvense* | 9.76 (10.8) | 0.70-44.7 | 1195(721) | 140-2825 |
| *Equisetum fluviatile* | 9.81 (14.2) | 0.30-61.5 | 1140(650) | 140-2825 |
| *Equisetum variegatum* | 3.33 (4.65) | 0.30-21.4 | 1622(596) | 140-2676 |
| *Eupatorium perfoliatum* | 5.89 (7.18) | 0.30-30.4 | 1356(709) | 140-2825 |
| *Hypericum virginicum* | 17.5 (18.1) | 0.60-61.5 | 780(537) | 140-2320 |
| *Iris versicolor* | 8.88 (12.2) | 1.20-38.2 | 1031(404) | 152-1403 |
| *Juncus articulatus* | 8.80 (12.5) | 0.30-49.7 | 1121(647) | 140-2676 |
| *Juncus effusus* | 29.0 (18.6) | 8.90-61.5 | 392(172) | 163-666 |
| *Lycopus uniflorus* | 9.52 (13.1) | 0.60-50.3 | 1125(631) | 140-2332 |
| *Lysimachia terrestris* | 11.0 (15.1) | 0.60-61.5 | 1027(568) | 140-2343 |
| *Onoclea sensibilis* | 16.5 (16.0) | 0.90-50.5 | 792(513) | 152-1685 |
| *Osmunda regalis* | 4.00 (3.40) | 1.20-12.0 | 1391(415) | 607-2018 |
| *Polytrichum commune* | 17.5 (17.1) | 1.40-49.4 | 917(658) | 169-2218 |
| *Prunella vulgaris* | 2.44 (2.28) | 0.50-10.7 | 1548(478) | 517-2594 |
| *Rubus pubescens* | 13.4 (13.8) | 0.60-44.7 | 893(506) | 217-1787 |
| *Solidago canadensis* | 13.4 (15.6) | 1.20-4.47 | 956(701) | 212-2179 |
| *Solidago rugosa* | 34.1 (17.7) | - | 423(312) | - |
| *Spiraea latifolia* | 15.7 (18.0) | 0.70-61.5 | 999(662) | 152-2594 |
| *Thalictrum polygamum* | 9.25 (13.1) | 0.60-44.7 | 1191(560) | 217-2332 |
| *Viola pallens* | 12.5 (17.1) | 0.30-61.5 | 1234(748) | 140-2676 |

Table 9. Soil arsenic concentrations for sites at which each of 33 species were found.

| Species | n | Total acid extractable Arsenic (ppm) Mean (SD) | Range | Total water extractable Arsenic (ppm) Mean (SD) | Range |
|---|---|---|---|---|---|
| Maximum range | | | 70.0-25900 | | 0.85-745 |
| *Agrostis palustris* | 72 | 2110(4000) | 89.1-25900 | 72.2(127) | 0.85-745 |
| *Alnus rugosa* | 42 | 1540(2020) | 98.7- 7600 | 43.4 (68.3) | 0.85-423 |
| *Aster lateriflorus* | 13 | 1250(1330) | 89.1- 4700 | 56.9 (40.2) | 5.75-126 |
| *Aster novi-belgii* | 53 | 2070(4490) | 204 -25900 | 79.1(148) | 0.85-745 |
| *Aster umbellatus* | 29 | 1760(2240) | 98.7- 8600 | 50.0 (77.9) | 2.12-423 |
| *Campylium stellata* | 50 | 1800(2939) | 89.1-16900 | 63.1(117) | 0.85-710 |
| *Carex brunessens* | 9 | 1940(2873) | 98.7- 7600 | 18.2 (9.77) | 1.55- 35.0 |
| *Carex viridula* | 32 | 868(1160) | 130 - 6300 | 53.2(125) | 0.85-710 |
| *Centaurea nigra* | 22 | 1930(5430) | 89.1-25900 | 50.8 (68.2) | 1.21-317 |
| *Chara globularis* | 8 | 445 (141) | 313 - 717 | 17.6 (13.8) | 4.83- 35.9 |
| *Chrysanthemum leucanthemum* | 21 | 1440(3570) | 89.1-16900 | 40.6 (28.2) | 2.25-118 |
| *Dryopteris thelypteris* | 16 | 3030(6340) | 204 -25900 | 76.0 (88.9) | 1.33-317 |
| *Equisetum arvense* | 53 | 2912(4730) | 89.1-25900 | 87.8(126) | 0.85-745 |
| *Equisetum fluviatile* | 105 | 2080(3720) | 70.0-25900 | 64.1(112) | 0.85-745 |
| *Equisetum variegatum* | 33 | 1720(2770) | 89.1-12300 | 94.1(175) | 1.21-745 |
| *Eupatorium perfoliatum* | 46 | 2720(4928) | 89.1-25900 | 76.7(123) | 0.85-745 |
| *Hypericum virginicum* | 38 | 3086(4640) | 98.7-25900 | 56.4 (77.6) | 0.85-317 |
| *Iris versicolor* | 9 | 486 (372) | 169 - 1330 | 20.4 (8.30) | 6.18- 35.0 |
| *Juncus articulatus* | 53 | 2120(3950) | 70.0-25900 | 50.4 (69.4) | 0.85-317 |
| *Juncus effusus* | 11 | 3420(2960) | 478 - 8600 | 38.5 (41.6) | 2.12-116 |
| *Lycopus uniflorus* | 64 | 1800(3990) | 70.0-25900 | 48.1 (67.8) | 0.85-423 |
| *Lysimachia terrestris* | 47 | 2540(4160) | 70.0-25900 | 54.6 (67.8) | 1.33-317 |
| *Onoclea sensibilis* | 21 | 2460(3880) | 89.1-16900 | 61.5 (93.6) | 2.12-423 |
| *Osmunda regalis* | 8 | 2010(2070) | 351 - 3470 | 53.6 (70.6) | 1.33-215 |
| *Polytrichum commune* | 12 | 3690(3700) | 289 -12300 | 118 (205) | 2.12-745 |
| *Prunella vulgaris* | 36 | 1110(1550) | 89.1- 8590 | 66.2(117) | 1.21-710 |
| *Rubus pubescens* | 15 | 580 (395) | 98.7- 1710 | 31.1 (23.7) | 6.52-105 |
| *Solidago canadensis* | 10 | 583 (447) | 196 - 1710 | 27.5 (16.5) | 6.18- 55.7 |
| *Solidago rugosa* | 6 | 595 (256) | 354 - 1040 | 21.2 (11.0) | 6.52- 39.5 |
| *Spiraea latifolia* | 55 | 1720(2090) | 89.1- 8620 | 55.2 (74.9) | 0.85-423 |
| *Thalictrum polygamum* | 23 | 1360(3410) | 98.7- 1710 | 29.0 (23.2) | 6.18-118 |
| *Viola pallens* | 55 | 2610(4610) | 89.1-25900 | 68.5(113) | 0.85-745 |

Table 10. Soil mercury concentrations for sites at which each of 33 species was was found.

| Species | n | Total acid extractable Mercury (ppm) |  | Total water extractable Mercury (ppm) |  |
|---|---|---|---|---|---|
|  |  | mean (SD) | range | mean (SD) | range |
| Maximum range |  |  | 0.670- 8.94 |  | 0.001-0.290 |
| *Agrostis palustris* | 72 | 3.35(1.89) | 1.05 - 8.93 | 0.052(0.054) | 0.004-0.290 |
| *Alnus rugosa* | 42 | 3.35(2.01) | 0.670- 8.43 | 0.044(0.050) | 0.001-0.290 |
| *Aster lateriflorus* | 13 | 3.10(1.57) | 1.15 - 6.86 | 0.078(0.064) | 0.016-0.209 |
| *Aster novi-belgii* | 53 | 3.25(1.73) | 0.968- 8.43 | 0.052(0.057) | 0.002-0.290 |
| *Aster umbellatus* | 29 | 3.73(2.41) | 0.968- 8.94 | 0.061(0.070) | 0.002-0.290 |
| *Campylium stellata* | 50 | 3.22(1.84) | 1.05 - 8.43 | 0.060(0.058) | 0.005-0.290 |
| *Carex brunessens* | 9 | 2.80(1.74) | 0.968- 6.56 | 0.016(0.015) | 0.001-0.043 |
| *Carex viridula* | 32 | 2.68(1.26) | 0.670- 7.49 | 0.035(0.025) | 0.004-0.110 |
| *Centaurea nigra* | 22 | 3.18(1.53) | 1.27 - 7.16 | 0.047(0.045) | 0.009-0.204 |
| *Chara globularis* | 8 | 4.46(1.90) | 2.59 - 8.39 | 0.028(0.021) | 0.006-0.062 |
| *Chrysanthemum leucanthemum* | 21 | 2.66(1.58) | 1.27 - 8.18 | 0.050(0.061) | 0.004-0.226 |
| *Dryopteris thelypteris* | 16 | 3.37(1.54) | 1.64 - 7.16 | 0.058(0.054) | 0.005-0.209 |
| *Equisetum arvense* | 53 | 3.83(2.12) | 1.05 - 8.93 | 0.058(0.061) | 0.002-0.290 |
| *Equisetum fluviatile* | 105 | 3.37(1.86) | 0.670- 8.93 | 0.045(0.049) | 0.001-0.290 |
| *Equisetum variegatum* | 33 | 2.90(1.79) | 1.05 - 8.93 | 0.052(0.053) | 0.004-0.226 |
| *Eupatorium perfoliatum* | 46 | 3.58(2.12) | 1.05 - 8.93 | 0.044(0.049) | 0.002-0.226 |
| *Hypericum virginicum* | 38 | 3.97(2.04) | 1.09 - 8.93 | 0.034(0.050) | 0.001-0.114 |
| *Iris versicolor* | 9 | 2.21(0.94) | 1.14 - 4.29 | 0.022(0.015) | 0.009-0.055 |
| *Juncus articulatus* | 53 | 3.25(1.65) | 1.05 - 8.93 | 0.033(0.037) | 0.002-0.209 |
| *Juncus effusus* | 11 | 4.87(2.07) | 1.52 - 7.49 | 0.030(0.021) | 0.001-0.075 |
| *Lycopus uniflorus* | 64 | 3.18(1.86) | 0.670- 8.93 | 0.045(0.052) | 0.001-0.290 |
| *Lysimachia terrestris* | 47 | 3.54(1.88) | 1.09 - 8.93 | 0.039(0.047) | 0.001-0.290 |
| *Onoclea sensibilis* | 21 | 3.91(2.48) | 0.968- 8.94 | 0.063(0.058) | 0.001-0.272 |
| *Osmunda regalis* | 8 | 3.80(2.37) | 1.09 - 8.94 | 0.090(0.099) | 0.009-0.272 |
| *Polytrichum commune* | 12 | 4.80(2.20) | 0.968- 8.43 | 0.090(0.080) | 0.001-0.290 |
| *Prunella vulgaris* | 36 | 2.91(1.18) | 1.27 - 5.73 | 0.045(0.047) | 0.004-0.209 |
| *Rubus pubescens* | 15 | 2.66(1.58) | 1.14 - 6.07 | 0.035(0.023) | 0.006-0.089 |
| *Solidago canadensis* | 10 | 2.15(0.63) | 1.52 - 3.43 | 0.043(0.067) | 0.001-0.225 |
| *Solidago rugosa* | 6 | 3.19(1.04) | 2.07 - 4.68 | 0.043(0.025) | 0.001-0.064 |
| *Spiraea latifolia* | 55 | 3.43(1.84) | 0.670- 8.94 | 0.053(0.058) | 0.001-0.290 |
| *Thalictrum polygamum* | 23 | 2.45(1.63) | 1.09 - 8.18 | 0.024(0.018) | 0.001-0.063 |
| *Viola pallens* | 55 | 3.56(2.01) | 1.07 - 8.93 | 0.050(0.055) | 0.001-0.290 |

Table 11. Correlations (r) between species biomass and various physical and chemical parameters. Levels of significance are presented in parentheses.

| Species | Depth to Water Table | Soil Organic Matter Content | Thickness of Soil Organic Matter Layer |
|---|---|---|---|
| *Agrostis palustris* | | | -0.23(0.026) |
| *Alnus rugosa* | 0.46(0.001) | | |
| *Aster lateriflorus* | | | |
| *Aster novi-belgii* | 0.26(0.028) | 0.27(0.026) | |
| *Aster umbellatus* | | | |
| *Campylium stellata* | | -0.25(0.038) | -0.29(0.020) |
| *Carex brunessens* | | | |
| *Carex viridula* | | | |
| *Centaurea nigra* | | | |
| *Chara globularis* | -0.88(0.002) | | |
| *Chrysanthemum leucanthemum* | | | |
| *Dryopteris thelypteris* | | | |
| *Equisetum arvense* | | | |
| *Equisetum fluviatile* | | -0.25(0.005) | |
| *Equisetum variegatum* | | | |
| *Eupatorium perfoliatum* | | 0.36(0.007) | 0.28(0.029) |
| *Hypericum virginicum* | | | 0.30(0.032) |
| *Iris versicolor* | | | |
| *Juncus articulatus* | -0.51(<0.001) | | 0.45(<0.001) |
| *Juncus effusus* | | | |
| *Lycopus uniflorus* | | | |
| *Lysimachia terrestris* | | | |
| *Onoclea sensibilis* | | | |
| *Osmunda regalis* | | | |
| *Polytrichum commune* | | | |
| *Prunella vulgaris* | | | |
| *Rubus pubescens* | | | |
| *Solidago canadensis* | | | |
| *Solidago rugosa* | | 0.88(0.010) | |
| *Spiraea latifolia* | 0.34(0.005) | 0.55(<0.001) | |
| *Thalictrum polygamum* | | | |
| *Viola pallens* | | | |

Table 11. (cont'd.)

| Species | Soil Bulk Density | Weight of the Soil Sink Fraction | Weight of the Soil Float Fraction |
|---|---|---|---|
| *Agrostis palustris* | 0.30(0.005) | 0.32(0.003) | |
| *Alnus rugosa* | | | |
| *Aster lateriflorus* | | | |
| *Aster novi-belgii* | | | |
| *Aster umbellatus* | | | |
| *Campylium stellata* | | | 0.35(0.006) |
| *Carex brunessens* | | | |
| *Carex viridula* | | | |
| *Centaurea nigra* | | | |
| *Chara globularis* | -0.69(0.028) | -0.76(0.014) | |
| *Chrysanthemum leucanthemum* | | | |
| *Dryopteris thelypteris* | | | |
| *Equisetum arvense* | 0.37(0.003) | 0.37(0.004) | |
| *Equisetum fluviatile* | 0.32(<0.001) | 0.35(<0.001) | |
| *Equisetum variegatum* | | | |
| *Eupatorium perfoliatum* | | | |
| *Hypericum virginicum* | | | |
| *Iris versicolor* | | | |
| *Juncus articulatus* | -0.25(0.037) | | |
| *Juncus effusus* | | 0.65(0.016) | |
| *Lycopus uniflorus* | | | |
| *Lysimachia terrestris* | | | |
| *Onoclea sensibilis* | | | |
| *Osmunda regalis* | | | |
| *Polytrichum commune* | | | |
| *Prunella vulgaris* | | | |
| *Rubus pubescens* | | | |
| *Solidago canadensis* | | | |
| *Solidago rugosa* | | | |
| *Spiraea latifolia* | -0.47(<0.001) | -0.46(<0.001) | |
| *Thalictrum polygamum* | | | |
| *Viola pallens* | | | |

Table 11. (cont'd.)

| Species | Weight of Coarse Organic Matter in the Soil | Total Acid Extractable Arsenic | Total Water Soluble Arsenic |
|---|---|---|---|
| *Agrostis palustris* | -0.20(0.048) | | 0.26(0.014) |
| *Alnus rugosa* | | | |
| *Aster lateriflorus* | | | |
| *Aster novi-belgii* | | 0.30(0.015) | |
| *Aster umbellatus* | | | |
| *Campylium stellata* | -0.28(0.023) | | |
| *Carex brunessens* | | 0.66(0.026) | |
| *Carex viridula* | | 0.31(0.045) | |
| *Centaurea nigra* | | | |
| *Chara globularis* | | | 0.89(0.021) |
| *Chrysanthemum leucanthemum* | | | |
| *Dryopteris thelypteris* | | | |
| *Equisetum arvense* | | | 0.25(0.034) |
| *Equisetum fluviatile* | | | |
| *Equisetum variegatum* | | | |
| *Eupatorium perfoliatum* | | | |
| *Hypericum virginicum* | | | |
| *Iris versicolor* | | | |
| *Juncus articulatus* | 0.46(<0.001) | | |
| *Juncus effusus* | 0.54(0.043) | | 0.68(0.011) |
| *Lycopus uniflorus* | | | |
| *Lysimachia terrestris* | | | |
| *Onoclea sensibilis* | | 0.70(<0.001) | |
| *Osmunda regalis* | | | |
| *Polytrichum commune* | | | |
| *Prunella vulgaris* | | | |
| *Rubus pubescens* | | | |
| *Solidago canadensis* | | | |
| *Solidago rugosa* | | 0.78(0.033) | |
| *Spiraea latifolia* | | 0.29(0.012) | |
| *Thalictrum polygamum* | | | |
| *Viola pallens* | | | 0.35(0.005) |

Table 11. (cont'd.)

| Species | Total Acid Extractable Mercury | Total Water Soluble Mercury |
|---|---|---|
| *Agrostis palustris* | | |
| *Alnus rugosa* | | |
| *Aster lateriflorus* | | |
| *Aster novi-belgii* | 0.37(0.004) | |
| *Aster umbellatus* | | |
| *Campylium stellata* | | |
| *Carex brunessens* | 0.79(0.005) | |
| *Carex viridula* | | |
| *Centaurea nigra* | | |
| *Chara globularis* | | |
| *Chrysanthemum leucanthemum* | | |
| *Dryopteris thelypteris* | | |
| *Equisetum arvense* | | |
| *Equisetum fluviatile* | | |
| *Equisetum variegatum* | | |
| *Eupatorium perfoliatum* | 0.37(0.005) | |
| *Hypericum virginicum* | | |
| *Iris versicolor* | | |
| *Juncus articulatus* | | -0.28(0.025) |
| *Juncus effusus* | | |
| *Lycopus uniflorus* | | |
| *Lysimachia terrestris* | | |
| *Onoclea sensibilis* | | |
| *Osmunda regalis* | | |
| *Polytrichum commune* | | |
| *Prunella vulgaris* | | 0.35(0.018) |
| *Rubus pubescens* | | |
| *Solidago canadensis* | | |
| *Solidago rugosa* | | |
| *Spiraea latifolia* | 0.31(0.009) | 0.29(0.016) |
| *Thalictrum polygamum* | | |
| *Viola pallens* | | |

Table 12. Tissue concentrations of arsenic and mercury in species found on the Oldham tailings.

| | | Arsenic (ppm) | | Mercury (ppm) | |
|---|---|---|---|---|---|
| Species | n | Mean(SD) | range | Mean(SD) | range |
| *Agrostis palustris* | 43 | 53.8(86.0) | 4-400 | 0.171(0.117) | 0.058-0.487 |
| *Alnus rugosa* | 30 | 34.7(58.5) | 4-298 | 0.125(0.044) | 0.066-0.272 |
| *Aster lateriflorus* | 8 | 9.00(6.59) | 3-21 | 0.073(0.039) | 0.020-0.106 |
| *Aster novi-belgii* | 26 | 6.41(4.85) | 3-24 | 0.162(0.108) | 0.036-0.423 |
| *Aster umbellatus* | 24 | 5.08(2.95) | 2-14 | 0.113(0.081) | 0.040-0.408 |
| *Campyllium stellata* | 36 | 218(276) | 3-1480 | 2.10(1.76) | 0.560-8.86 |
| *Carex brunessens* | 6 | 5.50(4.23) | 2-13 | 0.055(0.029) | <0.003-0.074 |
| *Carex viridula* | 8 | 13.6(12.3) | 2-36 | 0.194(0.142) | 0.050-0.424 |
| *Centaurea nigra* | 13 | 6.93(7.98) | 2-32 | 0.190(0.122) | 0.081-0.503 |
| *Chara globularis* | 8 | 1730(3350) | 368-10,000 | 0.452(0.112) | 0.322-0.660 |
| *Chrysanthemem leucanthemum* | 11 | 43.8(74.7) | 2-248 | 0.177(0.102) | 0.026-0.330 |
| *Dryopteris thelypteris* | 12 | 14.0(33.4) | 3-120 | 0.127(0.052) | 0.070-0.238 |
| *Equisetum arvense* | 38 | 16.0(24.6) | 4-124 | 0.338(0.260) | 0.068-1.134 |
| *Equisteum fluviatile* | 74 | 45.3(91.4) | 3-536 | 0.225(0.198) | 0.034-1.47 |
| *Equisetum variegatum* | 22 | 26.7(73.7) | 2-348 | 0.108(0.063) | 0.040-0.252 |
| *Eupatorium perfoliatum* | 27 | 59.6(88.5) | 3-332 | 0.263(0.301) | 0.018-1.43 |
| *Hypericum virginicum* | 13 | 21.2(31.4) | 3-112 | 0.159(0.151) | 0.040-0.470 |
| *Iris versicolor* | 7 | 16.1(28.7) | 2-80 | 0.037(0.021) | 0.014-0.070 |
| *Juncus articulatus* | 31 | 15.6(27.0) | 3-120 | 0.101(0.078) | 0.010-0.424 |
| *Juncus effusus* | 9 | 4.89(3.10) | 3-11 | 0.064(0.037) | 0.026-0.127 |
| *Lycopus uniflorus* | 17 | 13.5(19.6) | 2-80 | 0.194(0.119) | 0.030-0.579 |
| *Lysimachia terrestris* | 21 | 10.2(9.02) | 3-36 | 0.136(0.092) | 0.040-0.446 |
| *Onoclea sensibilis* | 15 | 5.40(7.58) | 3-32 | 0.157(0.088) | 0.062-0.317 |
| *Osmunda regalis* | 5 | 4.20(2.17) | 3-8 | 0.077(0.026) | 0.036-0.102 |
| *Polytrichum commune* | 8 | 420(799) | 3-2360 | 2.264(1.62) | 0.430-4.490 |
| *Prunella vulgaris* | 13 | 16.4(23.1) | 2-80 | 0.258(0.136) | 0.130-0.640 |
| *Rubus pubescens* | 10 | 16.1(40.7) | 2-132 | 0.096(0.050) | 0.046-0.228 |
| *Solidago canadensis* | 7 | 3.14(0.90) | 2-4 | 0.061(0.044) | 0.022-0.144 |
| *Solidago rugosa* | 6 | 2.33(0.52) | 2-3 | 0.041(0.019) | 0.002-0.054 |
| *Spiraea latifolia* | 34 | 25.7(28.8) | 2-100 | 0.158(0.108) | 0.066-0.668 |
| *Thalictrum polygamum* | 8 | 4.50(3.30) | 2-10 | 0.083(0.058) | 0.028-0.200 |
| *Viola pallens* | 8 | 119(196) | 5-560 | 0.536(0.373) | 0.043-1.132 |

Table 13. Mean arsenic and mercury accumulation indices for species found on the Oldham tailings.

| Species | n | Arsenic Accumulation Index Mean±SE | Arsenic Accumulation Index Range | Mercury Accumulation Index Mean±SE | Mercury Accumulation Index Range |
|---|---|---|---|---|---|
| *Agrostis palustris* | 72 | 3.34±1.25 | 0.01- 45.2 | 6.46±1.19 | 0.31- 40.1 |
| *Alnus rugosa* | 42 | 1.51±0.42 | 0.04- 9.60 | 4.94±0.83 | 0.94- 17.8 |
| *Aster lateriflorus* | 13 | 0.22±0.05 | 0.10- 0.52 | 1.31±0.39 | 0.36- 3.21 |
| *Aster novi-belgii* | 53 | 0.26±0.08 | 0.03- 2.10 | 6.29±1.24 | 0.29- 26.7 |
| *Aster umbellatus* | 29 | 0.32±0.10 | 0.01- 2.35 | 4.02±1.03 | 0.23- 23.2 |
| *Campylium stellata* | 50 | 20.2 ±7.47 | 0.14-230.0 | 62.2±11.4 | 4.31-307.0 |
| *Carex brunessens* | 9 | 1.08±0.70 | 0.11- 4.52 | 8.30±4.25 | 0.05- 23.2 |
| *Carex viridula* | 32 | 0.63±0.15 | 0.19- 1.16 | 12.2 ±5.30 | 1.82- 42.3 |
| *Centaurea nigra* | 22 | 1.08±0.54 | 0.04- 6.02 | 5.74±1.41 | 2.18- 20.4 |
| *Chara globularis* | 8 | 445 ±407 | 13.4-2070 | 30.5±14.6 | 5.36- 87.3 |
| *Chrysanthemum leucanthemum* | 21 | 1.11±0.43 | 0.03- 3.89 | 7.34±2.24 | 0.64- 24.6 |
| *Dryopteris thelypteris* | 16 | 0.92±0.54 | 0.01- 5.17 | 6.31±2.38 | 0.53- 28.3 |
| *Equisetum arvense* | 53 | 0.99±0.65 | 0.01- 24.9 | 13.9 ±2.69 | 1.16- 82.7 |
| *Equisetum fluviatile* | 105 | 1.93±0.47 | 0.01- 21.1 | 11.4 ±2.07 | 0.73-140.0 |
| *Equisetum variegatum* | 33 | 2.62±2.23 | 0.01- 49.5 | 5.42±1.44 | 0.43- 28.7 |
| *Eupatorium perfoliatum* | 46 | 1.40±0.45 | 0.06- 9.38 | 12.7 ±3.72 | 0.35- 87.1 |
| *Hypericum virginicum* | 38 | 1.03±0.37 | 0.02- 4.69 | 7.77±1.93 | 0.44- 19.7 |
| *Iris versicolor* | 9 | 0.63±0.30 | 0.11- 2.29 | 3.83±1.34 | 0.67- 9.96 |
| *Juncus articulatus* | 53 | 1.26±0.56 | 0.01- 16.7 | 6.19±0.92 | 0.48- 19.9 |
| *Juncus effusus* | 11 | 0.27±0.14 | 0.06- 1.41 | 2.22±0.33 | 0.59- 3.85 |
| *Lycopus uniflorus* | 64 | 0.81±0.34 | 0.05- 5.86 | 18.0±10.8 | 1.23-178.0 |
| *Lysimachia terrestris* | 47 | 0.91±0.46 | 0.03- 9.77 | 11.7± 3.51 | 0.57- 66.6 |
| *Onoclea sensibilis* | 21 | 0.21±0.10 | 0.01- 1.51 | 3.04±0.45 | 0.99- 6.35 |
| *Osmunda regalis* | 8 | 0.08±0.02 | 0.01- 0.15 | 3.26±2.11 | 0.27- 11.3 |
| *Polytrichum commune* | 12 | 4.15±1.70 | 0.04- 11.9 | 35.1± 8.34 | 5.39- 67.5 |
| *Prunella vulgaris* | 36 | 1.49±1.05 | 0.02- 13.9 | 7.70±2.07 | 1.17- 28.0 |
| *Rubus pubescens* | 15 | 0.28±0.12 | 0.04- 1.26 | 3.91±1.01 | 0.72- 11.30 |
| *Solidago canadensis* | 10 | 0.14±0.04 | 0.05- 0.33 | 11.3± 9.12 | 0.14- 65.8 |
| *Solidago rugosa* | 6 | 0.14±0.04 | 0.05- 0.31 | 8.45±7.84 | 0.05- 39.8 |
| *Spiraea latifolia* | 55 | 0.94±0.25 | 0.01- 7.06 | 5.46±1.47 | 0.85- 44.5 |
| *Thalictrum polygamum* | 23 | 0.22±0.10 | 0.05- 0.86 | 4.07±0.44 | 2.80- 6.35 |
| *Viola pallens* | 55 | 6.96±5.51 | 0.08- 45.2 | 23.9±12.1 | 0.58-107.1 |

Table 14. Correlations (r) of tissue arsenic and mercury concentrations with soil arsenic and mercury concentrations.

| Species | Total Acid Extractable Arsenic | Total Water Soluble Arsenic | Total Acid Extractable Mercury | Total Water Soluble Mercury |
|---|---|---|---|---|
| *Agrostis palustris* | | | | |
| *Alnus rugosa* | | 0.67(<0.001) | | |
| *Aster lateriflorus* | | | | 0.73(0.020) |
| *Aster novi-belgii* | | | | |
| *Aster umbellatus* | | 0.55(0.004) | | |
| *Campylium stellata* | 0.55(<0.001) | 0.29(0.046) | 0.70(<0.001) | |
| *Carex brunessens* | | | | |
| *Carex viridula* | | | | |
| *Centaurea nigra* | 0.55(0.027) | 0.58(0.025) | 0.88(<0.001) | 0.71(0.003) |
| *Chara globularis* | | | | |
| *Chrysanthemum leucanthemum* | | | | |
| *Dryopteris thelypteris* | | | 0.89(<0.001) | 0.79(0.002) |
| *Equisetum arvense* | | 0.30(0.034) | | |
| *Equisetum fluviatile* | | | 0.39(<0.001) | |
| *Equisetum variegatum* | | | | |
| *Eupatorium perfoliatum* | 0.42(0.015) | | | |
| *Hypericum virginicum* | | | | |
| *Iris versicolor* | | | 0.86(0.006) | 0.82(0.012) |
| *Juncus articulatus* | | 0.45(0.007) | 0.30(0.049) | |
| *Juncus effusus* | | 0.71(0.017) | | 0.81(0.004) |
| *Lycopus uniflorus* | 0.41(0.050) | 0.73(0.001) | | |
| *Lysimachia terrestris* | | | | |
| *Onoclea sensibilis* | 0.66(0.004) | 0.61(0.014) | 0.84(<0.001) | |
| *Osmunda regalis* | | | | |
| *Polytrichum commune* | 0.77(0.013) | | | |
| *Prunella vulgaris* | | | 0.56(0.023) | |
| *Rubus pubescens* | | | | 0.87(0.001) |
| *Solidago canadensis* | | | | |
| *Solidago rugosa* | | | | |
| *Spiraea latifolia* | | | | |
| *Thalictrum polygamum* | | 0.92(0.001) | | |
| *Viola pallens* | | | 0.88(0.002) | 0.91(0.001) |

Negatively correlated with thickness of the organic matter layer and the weight of coarse organic material in the soils (Table 11).

Tissue Arsenic Concentrations: range = 4-440 ppm, mean = 53.8 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.058-0.487 ppm, mean = 0.171 ppm; not significantly correlated with soil mercury concentrations.

Agrostis palustris was one of the most common species found on the Oldham tailings. It was generally most abundant in the herbaceous plant communities and was a co-dominant species in the Equisetum arvense - Agrostis palustris and Equisetum fluviatile - Agrostis palustris communities.

Best growth generally occurred in sandy areas with relatively little organic matter (Table 8), hence the correlation with the weight of the soil sink fraction. A. palustris was found throughout the range of soil arsenic and mercury concentrations (Tables 9 and 10). High biomass was often associated with elevated concentrations of these metals in the soil indicating that this species is tolerant of both arsenic and mercury. Positive correlations of biomass with soil arsenic concentrations may indicate that this species achieves a competitive edge when growing in areas highly contaminated with arsenic. Tissue arsenic concentrations were high in A. palustris while tissue mercury concentrations were in the middle range. The arsenic accumulation index for this species was very high (Table 13). The mercury accumulation index was moderate in comparison to other species.

Alnus rugosa (speckled alder)

Biomass: positively correlated with depth to water table (Table 11).

Tissue Arsenic Concentration: range for foliage = 4-298 ppm, mean = 34.7 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentration: range for foliage = 0.006-0.272 ppm, mean = 0.125 ppm; significantly correlated with the concentration of total water-soluble mercury in the soil.

Alnus rugosa had the largest average biomass of all the species found on the tailings. Large quantities of this species were restricted to the southern portion of the tailings area and along the boundary between the tailings and the surrounding forest.

The data indicate that the best growth of Alnus rugosa occurred on well-drained soils containing large amounts of organic material (Table 8). The large quantities of organic matter and low quantities of sand associated with the tailings underlying Alnus stands are a result of the presence of this species and are not necessarily a prerequisite for its growth since small A. rugosa were occassionally found on tailings containing little organic matter. Alnus rugosa is noted for its nitrogen-fixing capabilities which would increase plant productivity resulting in large inputs and subsequent accumulation of organic matter. This, in turn, would ameliorate site conditions, further increasing the productivity of the site.

This species was found throughout the range of soil arsenic and mercury concentrations with average soil arsenic concentrations in the low to moderate range and soil mercury concentrations in the middle range (Tables 9 and 10). Concentrations of mercury taken up by Alnus rugosa were moderate in comparison to other species. Mercury uptake was correlated with mercury concentrations in the soil. Although tissue mercury concentrations were moderate, the mercury accumulation index for this species was low, suggesting that it was able to limit mercury uptake (Table 13). Tissue arsenic concentrations were quite high in this species but was not correlated with any of the measurements of soil arsenic concentration. The arsenic accumulation index for this species was moderate in comparison to other species, possibly indicating some regulation of arsenic uptake (Table 13).

## Aster lateriflorus (calico aster)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 3-21 ppm, mean = 9.00 ppm; positively correlated with the concentration of total water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.020-0.106 ppm, mean = 0.073 ppm; not significantly correlated with any measurements of mercury concentrations in the soil.

Aster lateriflorus was found in a number of tailings plant communities, but it was not abundant in any of them. This species was characteristically found in dry areas on tailings containing very little organic matter (Table 8). The tailings where A. lateriflorus grew tended to have low concentrations of acid-extractable arsenic but moderate levels of water-soluble arsenic (Tables 9 and 10). Similarly, concentrations of acid-extractable mercury were low, while water-soluble mercury concentrations were very high. These results may suggest that A. lateriflorus may be somewhat sensitive to arsenic, but that it is tolerant of mercury. This is supported by the marked stunting noted for this species on the tailings, although seasonal droughtiness and poor mineral nutrition are probably also at least partially responsible for this stunting. Tissue arsenic concentrations were positively correlated with water-soluble arsenic concentrations in the soil, but only small concentrations were noted in the tissues. Tissue mercury concentrations were also low. The arsenic and mercury accumulation indices for A. lateriflorus were both low (Table 13), suggesting that arsenic and mercury toxicity were ameliorated by means of exclusion.

## Aster novi-belgii (New York aster)

Biomass: positively correlated with depth to water table; soil organic matter content; and concentrations of total acid-extractable arsenic in the soil, total acid-extractable mercury in the soil, and total water-soluble mercury in the soil (Table 11).

Tissue Arsenic Concentration: range = 3-24 ppm, mean = 6.41 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentration: range = 0.036-0.423 ppm, mean = 0.162 ppm; not significantly correlated with soil mercury concentrations.

Aster novi-belgii was found in all of the tailings plant communities with the exception of the Chara globularis - Equisetum fluviatile community. It was most abundant in the Equisetum arvense - Agrostis palustris and the Equisetum fluviatile - Agrostis palustris communities. A. novi-belgii was typically found growing in dry soils containing little organic matter and having high bulk density (Table 8). Aster novi-belgii was found throughout the full range of soil arsenic and mercury concentrations with average soil mercury concentrations in the middle range in comparison to other species (Tables 9 and 10). This species tended to be found on tailings with moderate concentrations of acid-extractable arsenic but high concentrations of water-soluble arsenic. There was a tendency for the biomass of A. novi-belgii to increase with increasing concentrations of arsenic and mercury in the soil suggesting that this species was tolerant of these metals. High arsenic and mercury concentrations may reduce the vigour of many potential competitors giving this species a competitive advantage. Moderate concentrations of mercury were found in the above-ground biomass of this species; however, arsenic concentrations were low. The mercury accumulation index for A. novi-belgii was moderate in comparison to other species, while the arsenic accumulation index was low (Table 13). These data suggest that A. novi-belgii probably copes with high arsenic concentrations by means of exclusion. A. novi-belgii growing on the tailings was stunted in comparison to A. novi-belgii growing on adjacent uncontaminated areas. This stunting was probably attributable to droughtiness and poor mineral nutrition associated with the areas of the tailings where this species was found. Although the data indicate that A. novi-belgii is very tolerant of both arsenic and mercury, some of the stunting may be attributable to metal toxicity.

Aster umbellatus (tall white aster)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 2-14 ppm, mean = 5.08 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.040-0.408 ppm, mean = 0.113 ppm; significantly correlated with the concentration of total water-soluble mercury in the soil (Table 14).

Aster umbellatus was found only in the understories of the various shrub communities. A. umbellatus was typically found on well-drained soils containing high concentrations of organic matter and having low bulk density (Table 8). Soil arsenic and mercury concentrations did not appear to affect the distribution of this species since it was found in a wide range of soil concentrations of both metals. A. umbellatus tended to grow best in the middle range of soil arsenic concentrations and in the high range of soil mercury concentrations (Tables 9 and 10). A. umbellatus grew much more vigorously than the other Aster species found on the tailings. A. umbellatus plants found on the tailings were only slightly smaller than plants growing on uncontaminated areas. The high vigor of this species is probably attributable to the fact that it tended to be found only in areas with ample quantities of organic matter in the soil. Organic matter would ameliorate the water and nutrient stresses associated with the tailings and would reduce concentrations of available arsenic and mercury. Tissue mercury concentrations were positively correlated with soil mercury concentrations, suggesting that A. umbellatus accumulated mercury; however, only relatively low concentrations of mercury were found in the tissues of this species, suggesting only limited uptake. Tissue arsenic concentrations were low. Both the arsenic and mercury accumulation indices were low for A. umbellatus, suggesting that this species was able to exclude these elements from its tissues (Table 13).

Campylium stellata (moss)

Biomass: Positively correlated with weight of soil float fraction, negatively correlated with thickness of organic matter layer, soil organic matter content and weight of coarse organic matter (Table 11).

Tissue Arsenic Concentrations: range = 3-1480 ppm, mean = 218 ppm; positively correlated with total acid-extractable arsenic (Table 14).

Tissue Mercury Concentrations: range = 0.560-8.86 ppm, mean = 2.10 ppm; positively correlated with the concentrations of total acid-extractable and water soluble-mercury in the soil (Table 14).

Campylium stellata occurred over most of the tailings except for areas containing permanent standing water. C. stellata was typically found growing as a mat over moderately well-drained tailings containing low concentrations of organic matter and having high bulk density. Best growth was achieved on tailings which were overlain by thin layers of organic matter (Table 8). These preferences are reflected in the negative correlation of C. stellata biomass with the thickness of the organic matter layer and soil organic matter content. The presence of this species on relatively bare tailings may be related to the fact that it is a calciphile. The tailings groundwater contains high concentrations of calcium which would be less available to C. stellata if it were insulated from this source of calcium by a thick layer of organic matter. The significant positive correlation with the soil float fraction suggests that this species may prefer tailings containing large quantities of clay-sized particles near the surface. Fine particles would retain soil water longer than sand, reducing the incidence of water stress to this species. C. stellata was found throughout the ranges of soil arsenic and mercury concentrations, suggesting that it is tolerant of both of these elements. Average soil concentrations tended to fall in the middle range with the exceptions of water-soluble mercury, which tended to be high in the soils on which C. stellata was found (Tables 9 and 10).

Tissue arsenic and mercury concentrations were correlated with the concentrations of acid-extractable arsenic and mercury in the soil, suggesting that this species was an accumulator of these metals. Tissue concentrations of both arsenic and mercury were extremely high in this species in comparison to other species found on the Oldham tailings. The arsenic and mercury accumulation indices for C. stellata were very high in comparison to other species, confirming that this species is an efficient accumulator of these elements. Mosses are noted for their high cation exchange capacity. It is likely that much of the tissue arsenic and mercury is adsorbed to the surfaces of C. stellata rather than incorporated within the plant cells.

Carex brunessens (sedge)

Biomass: positively correlated with the concentration of total acid-extractable arsenic and total water-soluble mercury in the soil (Table 11).

Tissue Arsenic Concentrations: range 2-13 ppm, mean = 5.50 ppm; not significantly correlated with concentrations of arsenic in the soil.

Tissue Mercury Concentrations: range = <0.003-0.074 ppm, mean = 0.055 ppm; not significantly correlated with concentrations of mercury in the soil.

Carex brunessens was found in several of the tailings plant communities, but it was not abundant at any location on the Oldham tailings. C. brunessens was typically found growing on very wet soils containing high quantities of organic matter and having low bulk density (Table 8). This species tended to grow in soils containing low concentrations of mercury and water-soluble arsenic and moderate concentrations of acid-extractable arsenic (Tables 9 and 10). These results suggest that C. brunessens may be somewhat sensitive to arsenic and mercury, particularly mercury. Tissue arsenic and mercury concentrations were low, falling within the ranges for vegetation growing on uncontaminated areas, suggesting that this species is an excluder of these elements.

Carex viridula (sedge)

Biomass: positively correlated with the concentration of total acid-extractable arsenic in the soil (Table 11).

Tissue Arsenic Concentrations: range = 2-36 ppm, mean = 13.6 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.050-0.424 ppm, mean = 0.194 ppm not significantly correlated with soil arsenic concentrations.

Carex viridula was found in most of the tailings plant communities but was most abundant in the Campylium stellata - Equisetum fluviatile community. C. viridula tended to grow on poorly drained tailings containing moderate concentrations of organic matter and having moderate bulk density (Table 8). This species occurred on a wide range of soil arsenic and mercury concentrations (Tables 9 and 10), but it tended to be found most frequently on soils containing fairly low concentrations of mercury and acid-extractable arsenic. Water-soluble arsenic in the soils where C. viridula was found tended to be moderate in comparison to soils in which other species grew. C. viridula biomass was positively correlated with soil arsenic concentrations, suggesting that this species was able to gain a competitive advantage over other species when growing on soils containing relatively high concentrations of arsenic. Tissue arsenic concentrations were low to moderate for this species. The arsenic accumulation index for C. viridula was low to moderate, suggesting that it may be able to exclude arsenic. Tissue concentrations of mercury were high as was the mercury accumulation index (Table 13), indicating that it is capable of accumulating this element.

Centaurea nigra (knapweed)

Biomass: not significantly correlated with any of the physical or chemical parameters measured.

Tissue Arsenic Concentrations: range = 2-32 ppm, mean = 6.93 ppm; positively correlated with concentrations of total acid-extractable arsenic and total water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.081-0.503 ppm, mean = 0.190 ppm; positively correlated with concentrations of total acid-extractable mercury and total water-soluble mercury in the soil (Table 14).

Centaurea nigra occurred most abundantly in the Campylium stellata-Equisetum fluviatile and Equisetum fluvatile - Agrostis palustris communities. C. nigra was typically found on moderately well-drained tailings containing low concentrations of organic matter and having moderately high soil bulk density (Table 8). This species was found throughout the entire range of arsenic and mercury concentrations and was most frequently found on soils containing moderate concentrations of arsenic and mercury (Tables 9 and 10). Tissue concentrations of arsenic were positively correlated with soil arsenic concentrations; however, this species accumulated relatively small concentrations of arsenic. Mercury concentrations in this species were fairly high and were correlated with soil mercury concentrations. The arsenic and mercury indices for this species were moderate in comparison to other species (Table 13), suggesting that C. nigra may be able to partially regulate the uptake of these elements.

Chara globularis (musk grass)

Biomass: negatively correlated with depth to water table, weight of the soil sink fraction and soil bulk density. Positively correlated with total water soluble arsenic (Table 11).

Tissue Arsenic Concentrations: range = 368-10,000 ppm, mean = 1730 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.322-0.660 ppm, mean = 0.452 ppm; not significantly correlated with soil mercury concentrations

The macro-algae *Chara globularis* was found only in a pond in the northeastern portion of the tailings area, its distribution restricted by its requirement for permanent standing water (Table 8). Maximum *Chara* biomass was found in the deepest portions of the pond. This corresponds to the findings of Andrews *et al*. (1) who found that *Chara hispida* did not occur in waters less than 5.5-m deep. They suggested the absence of *C. hispida* was due to either between-species competition or the lack of a suitable substrate for rhizome penetration in shallow areas. At Oldham *C. globularis* occurred in much shallower water. The most likely factor limiting its biomass in the shallower areas of the pond was ice scour. The negative correlations between *C. globularis* biomass and the weight of the soil sink fraction (sand) and soil bulk density may be spurious. Sandy tailings were found only in the shallowest portions of the pond where *C. globularis* biomass is probably affected most by ice scour.

Soil bulk density values for the pond sampling sites were in error since it was impossible to extract full-sized soil cores in the deeper areas where *C. globularis* grew best. The positive correlation between *Chara* biomass and water-soluble arsenic in the soil may indicate that the *Chara* mat on the bottom of the pond may create a boundary layer within which the concentration of the arsenic in the water is regulated by arsenic leaching out of the clay on the bottom of the pond. Alternatively, rhizomes and decumbent stems in contact with the clay may directly adsorb or absorb arsenic from the clay.

Tissue arsenic concentrations were extremely high in this species (up to 10,000 ppm) as were tissue mercury concentrations (up to 0.660 ppm). Arsenic and mercury accumulation indices were extremely high for *C. globularis* (Table 13). Efficient accumulation of arsenic and mercury by this species is probably largely attributable to adsorption of these elements to the surface of the plant.

### *Chrysanthemum leucanthemum* (ox-eye-daisy)

Biomass: not significantly correlated with any of the physical or chemical parameters measured.

Tissue Arsenic Concentrations: range = 0.026-0.330 ppm, mean = 43.8 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.026-0.330 ppm, mean = 0.177 ppm; not significantly correlated with soil arsenic concentrations.

*Chrysanthemum leucanthemum* was found primarily in the herbaceous plant communities with maximum abundance occurring in the *Equisetum fluviatile-Agrostis palustris* community. *C. leucanthemum* was generally found on relatively poorly drained tailings containing low concentrations of organic matter and having very high bulk density (Table 8). This species was present over a wide range of arsenic and mercury concentrations (Tables 9 and 10), indicating that it was tolerant of these elements. *C. leucanthemum* occurred most frequently on tailings containing low concentrations of arsenic and acid-extractable mercury. Average concentrations of water-soluble mercury in the tailings where this species was found were moderate. Tissue arsenic concentrations were high, and tissue mercury concentrations were moderate to high in comparison to other species. Arsenic and mercury accumulation indices were both moderate (Table 13), suggesting that accumulation of these elements may be regulated by *C. leucanthemum*.

### *Dryopteris thelypteris* (bog fern)

Biomass: not significantly correlated with any of the physical or chemical parameters measured.

Tissue Arsenic Concentrations: range = 3-120 ppm, mean = 14.0 ppm; positively correlated with the concentration of total acid-extractable and water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.070-0.238 ppm, mean = 0.127 ppm; not significantly correlated with soil mercury concentrations.

*Dryopteris thelypteris* was found in scattered patches throughout the study area, but it was most abundant in the *Equisetum arvense - Equisetum fluviatile* community. *D. thelypteris* was typically found growing on well-drained tailings containing moderate concentrations of organic matter and having moderate bulk density (Table 8). This species was present throughout the range of soil arsenic and mercury concentrations found in the study area. It was found most frequently on soils containing high concentrations of arsenic and water-soluble mercury (Tables 9 and 10). Average concentrations of acid-extractable mercury in the tailings where this species was found were moderate. Tissue arsenic concentrations were positively correlated with concentrations of arsenic in the soil, indicating that *Dryopteris* is tolerant of this metal. Tissue arsenic and mercury concentrations tended to be low to moderate for this species. The arsenic and mercury accumulation indices were both moderate for *D. thelypteris*, suggesting that it may be able to partially regulate the uptake of these elements.

### *Equisetum arvense* (field horsetail)

Biomass: positively correlated with the weight of soil sink fraction, soil bulk density, and the concentration of total water-soluble arsenic, and water-soluble mercury in the soil (Table 11).

Tissue Arsenic Concentrations: range = 4-124 ppm, mean = 16.0 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.068-1.128 ppm, mean = 0.338 ppm; positively correlated with the concentration of total water-soluble mercury in the soil (Table 14).

Equisetum arvense was one of the most common species on the Oldham tailings, and it was the dominant species in the Equisetum arvense - Agrostis palustris and Equisetum arvense - Equisetum fluviatile communities. The biomass of this species was greatest in areas where there was little organic matter (Table 8); hence, the positive correlation with weight of the soil sink fraction and soil bulk density. E. arvense was also most abundant on the eastern half of the tailings where arsenic concentrations tended to be highest. This is reflected in the positive correlation of E. arvense biomass with soil concentrations of these elements. Although this species was most frequently found on sites with high soil arsenic concentrations (Table 9), tissue arsenic concentrations were moderate. The arsenic accumulation index for E. arvense was moderate in comparison to other species, suggesting that this species tended to exclude arsenic. E. arvense was also frequently found growing on tailings containing high concentrations of water-soluble mercury (Table 10). Positive correlations of soil mercury concentrations with E. arvense tissue concentrations imply accumulation of this element. This was confirmed by the fact that the mercury accumulation index for this species was high. Tissue arsenic concentrations for E. arvense compare favourably with concentrations noted for this species at other tailings sites in Nova Scotia (Brooks et al. 1982, and Dale and Freedman 1982). Growth of E. arvense was vigorous in spite of the high concentrations of arsenic and mercury in the tailings where it was found.

Equisetum fluviatile (water horsetail)

Biomass: positively correlated with the weight of the soil sink fraction, soil bulk density. Negatively correlated with soil organic matter content (Table 11).

Tissue Arsenic Concentrations: range = 3-536 ppm, mean = 45.3 ppm; positively correlated with total acid-extractable arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.034-1.474 ppm, mean = 0.225 ppm; not significantly correlated with soil mercury concentrations.

Equisetum fluviatile was one of the most abundant species on the tailings. It was the only species found in all ten of the tailings plant communities, and it was a dominant or co-dominant species in four communities. E. fluviatile was found over a very broad range of site physical features. Mean values for depth to water table, soil organic matter content, thickness of the soil organic matter layer and soil bulk density all fell in the moderate range in comparison to other species (Table 8). The widespread distribution and success of E. fluviatile in both wet and dry communities may be at least partially attributable to the rooting strategy of this species.

The root systems of most species inhabiting the tailings were restricted to the upper 10 cm of the tailings. E. fluviatile rhizomes were unique in that they tended to penetrate deeply into the tailing forming an extensive network at the level of the summer water table. The sandy nature of the tailings makes areas of relatively high relief prone to seasonal drought. High areas may be dominated by species resistant to drought, while low areas are dominated by semi-aquatic species. The roots of E. fluviatile were always near water, so changes in elevation had little effect on the ability of this species to survive. Biomass of this species was low in areas dominated by shrubs. Inputs of organic matter by shrubs would improve the fertility and water-holding capacity of the soil, relieving seasonal droughtiness and increasing the competitive ability of plants rooted in the upper layers. The competitive advantage of E. fluviatile would be lost under these conditions, and its biomass would decline.

E. fluviatile was present throughout the ranges of soil arsenic and mercury concentrations (Tables 9 and 10), indicating that it is tolerant of both of these elements. Tissue arsenic concentrations increased as soil concentrations increased, and high concentrations of both arsenic and mercury were found in the tissues of this species. The range of tissue arsenic concentrations noted for E. fluviatile at Oldham are similar to those noted by Dale and Freedman (1982) and Brooks et al. (1981) for tailings sites in other locations in Nova Scotia. Arsenic and mercury accumulation indices for E. fluviatile were high in comparison to other species (Table 13).

### Equisetum variegatum (horsetail)

Biomass: not significantly correlated with any of the physical or chemical parameters measured.

Tissue Arsenic Concentrations: range = 2-348 ppm, mean = 26.7 ppm; not significantly correlated with concentrations of arsenic in the soil.

Tissue Mercury Concentrations: range = 0.040-0.252 ppm, mean = 0.108 ppm; not significantly correlated with concentrations of mercury in the soil.

Equisetum variegatum occurred frequently in the dry herbaceous communities achieving peak abundance in the Equisetum fluviatile - Agrostis palustris community. E. variegatum was typically found on well-drained tailings containing very low concentrations of organic matter and having high bulk density (Table 8). High biomass and frequency were maintained over a broad range of arsenic and mercury concentrations in the soil (Tables 9 and 10). E. variegatum tended to be found on tailings containing high concentrations of water-soluble arsenic and moderate concentrations of water-soluble mercury. Concentrations of acid-extractable arsenic in the soil tended to be moderate, while acid-extractable mercury concentrations were generally low. Tissue arsenic concentrations were fairly high; however, mercury tissue concentrations were low to moderate. The arsenic accumulation index for this species was high while the mercury accumulation index was low to moderate (Table 13). These results suggest that E. variegatum is capable of accumulating arsenic but copes with high concentrations of mercury in the soil by means of exclusion.

*Eupatorium perfoliatum* (boneset)

Biomass: positively correlated with thickness of organic matter layer, soil organic matter content, and concentration of total acid-extractable mercury in the soil (Table 11).

Tissue Arsenic Concentrations: range = 3-332 ppm, mean = 59.6 ppm; not significantly correlated with arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.018-1.430 ppm, mean = 0.263 ppm; positively correlated with the concentration of total water-soluble mercury in the soil (Table 14).

This species was generally restricted to the dry herbaceous communities, occurring most abundantly in the *Equisetum arvense* -*Agrostis palustris* and *Equisetum arvense* - *Equisetum fluviatile* communities. Best growth of this species was found on fairly dry sites with relatively thick layers of organic matter (Table 8). This species grew well on a wide range of acid-extractable arsenic and mercury concentrations. *E. perfoliatum* was most frequently encountered on soils containing high concentrations of arsenic and acid-extractable mercury (Tables 9 and 10). This species was generally found on tailings containing moderate concentrations of water-soluble mercury. Tissue arsenic concentrations were very high, but they were not correlated with soil concentrations. Mercury tissue concentrations were also high and were correlated with mercury concentrations in the soil. The arsenic and mercury accumulation indices were both high for *E. perfoliatum*, indicating that it is an accumulator of these elements (Table 13).

*Hypericum virginicum* (St. John's wort)

Biomass: positively correlated with organic matter depth (Table 11).

Tissue Arsenic Concentrations: range = 3-112 ppm, mean = 21.2 ppm; not significantly correlated with soil arsenic concentrations.

Tissue Mercury Concentrations: range = 0.040-0.470 ppm, mean = 0.159 ppm; not significantly correlated with soil mercury concentrations.

*Hypericum virginicum* was found in most tailings plant communities in small quantities. This species was most abundant in wet areas containing thick deposits of organic matter (Table 8) such as were found in the *Juncus articulatus* - *Equisetum fluviatile* and wet *Alnus rugosa* communities. *Hypericum* distribution did not appear to be limited by concentrations of arsenic and mercury in the soil (Tables 9 and 10). *H. virginicum* was most frequently encountered on soils containing high concentrations of acid-extractable arsenic and mercury but only moderate concentrations of water-soluble arsenic and mercury. The relatively low availability of arsenic and mercury in these soils may be attributable to complexing of these elements with the large quantities of organic matter found in them. The affinity of arsenic and mercury for soil organic matter has been documented in a number of studies (16) (19) (21). Tissue arsenic and mercury concentrations for this species were moderate in comparison with other species. Arsenic and mercury accumulation indices for H. virginicum were also moderate (Table 13), indicating a weak ability to accumulate these elements.

Iris versicolor (blue flag)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 2-80 ppm, mean = 16.1 ppm; positively correlated with concentrations of total acid-extractable arsenic and total water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.014-0.070 ppm, mean = 0.037 ppm; positively correlated with concentrations of total water-soluble mercury in the soil (Table 14).

Iris versicolor was a species of minor importance on the Oldham tailings. I. versicolor was most frequently found growing in poorly drained tailings covered with thick mats of peat (Table 8) and was generally restricted to areas with low soil arsenic and mercury concentrations (Tables 9 and 10). Tissue mercury concentrations were very low in this species as was the mercury accumulation index (Table 12). Tissue arsenic concentrations were moderate in comparison to other species on the tailings and were highly positively correlated with soil arsenic concentrations. The arsenic accumulation index for I. versicolor was moderate in comparison to other species (Table 13). The data suggest that I. versicolor is more sensitive to arsenic and mercury than most other tailings species and that it tends to exclude mercury and accumulates only relatively small quantities of arsenic up to a threshold value after which toxicity becomes apparent.

Juncus articulatus (rush)

Biomass: positively correlated with thickness of the organic matter layer, and the weight of coarse organic material in the soil sample. Negatively correlated with depth to water table, soil bulk density, and the concentration of total water-soluble mercury in the soil (Table 11).

Tissue Arsenic Concentrations: range = 3-120 ppm, mean = 15.6 ppm; positively correlated with the concentration of total acid-extractable arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.010-0.424 ppm, mean = 0.101 ppm; positively correlated with the concentration of total water-soluble mercury in the soil (Table 14).

*Juncus articulatus* was present in all but one of the tailings plant communities; however, it was abundant only in the *Juncus articulatus*-*Equisetum fluviatile* community. Growth of this species was best in wet areas containing shallow standing water and thick deposits of peat; hence, the positive correlations with these site factors. This species was found through almost the entire ranges of soil arsenic concentrations, although it tended to be found growing on soils with low concentrations of water-soluble mercury (Tables 9 and 10). This is confirmed by the negative correlation between *J. articulatus* biomass and the concentration of water-soluble mercury in the soil. These results suggest that *J. articulatus* is sensitive to high mercury concentrations. Tissue concentrations of arsenic and mercury were positively correlated with soil concentrations; however, concentrations in the tissues were low for mercury and moderate for arsenic. Arsenic and mercury accumulation indices for *J. articulatus* were both moderate, indicating that this species is not an efficient accumulator of either element (Table 13).

*Juncus effusus* (soft rush)

Biomass: positively correlated with the weight of soil sink fraction, the weight of coarse organic matter in the soil, and the concentrations of total water-soluble arsenic in the soil (Table 11).

Tissue Arsenic Concentrations: range = 3-11 ppm, mean = 4.89 ppm; positively correlated with the concentration of water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.026-0.127 ppm, mean = 0.064 ppm; positively correlated with concentrations of total water-soluble mercury in the soil (Table 14).

*Juncus effusus* was a species of minor importance on the Oldham tailings. It occurred most frequently in the shrub communities, particularly on wet sites with little overhead shrub cover. It was also common on the flood plain of Black Brook, where organic debris was deposited over sandy tailings. The preference of *J. effusus* for peaty soils is reflected in the correlation between its biomass and the weight of coarse organic matter in the soil. The soils on which this species was found were characterized by high concentrations of acid-extractable arsenic and mercury but low concentrations of water-soluble arsenic and mercury. Arsenic and mercury are readily bound to organic matter in the soil, reducing the amount that can be leached out of the soil by water (16) (19) (21). This would explain the low concentrations of water-soluble arsenic and mercury in the peaty soils on which *J. effusus* was found. The positive correlation between *J. effusus* biomass and the concentration of total water-soluble arsenic in the soil probably does not indicate that this species gains a competitive advantage in highly contaminated soils, since the sites with the highest soil arsenic concentrations and biomass were located in herbaceous areas while the sites with low soil arsenic concentrations were found in shrub thickets. Shading and root competition from the shrubs was probably the reason for low *J. effusus* biomass in the shrub thickets. This correlation, however, may indicate that *J. effusus* is fairly tolerant of arsenic and is restricted to soils containing low concentrations of water-soluble arsenic as a result of its preference for soils containing large quantities of organic matter.

Tissue arsenic and mercury concentrations were positively correlated with water-soluble soil concentrations of these elements; however, these concentrations were low in comparison to other species as were the arsenic and mercury accumulation indices (Table 13). These data suggest that J. effusus is an excluder of arsenic and mercury.

Lycopus uniflorus (bugle weed)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 2-80 ppm, mean = 13.5 ppm; not significantly correlated with arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.030-0.579 ppm, mean = 0.194 ppm; positively correlated with concentrations of total acid-extractable mercury and total water-soluble mercury in the soil (Table 14).

Lycopus uniflorus was widely distributed throughout the tailings area, occurring in all of the plant communities with the exception of the Chara globularis - Equisetum fluviatile community. It was most abundant in the Equisetum fluviatile - Agrostis palustris community; however, it contributed less than 2% of the total biomass of this community. Lycopus displayed a wide tolerance of site physical factors (Table 8). It was found on wet and dry sites; sites with and without large quantities of soil organic matter, and on open and shaded sites. Lycopus uniflorus was found primarily on tailings with moderate concentrations of acid-extractable arsenic but low concentrations of water-soluble arsenic (Table 9). Acid-extractable mercury tended to be low; however, water-soluble concentrations were moderate (Table 10). Tissue concentrations of arsenic were not correlated with arsenic concentrations in the soil and were at moderate levels in comparison to other species. The arsenic accumulation index for this species was moderate in comparison to other species (Table 13), suggesting that L. uniflorus was a relatively poor accumulator of arsenic. Concentrations of mercury in the tissues of this species were fairly high and were correlated with mercury concentrations in the soil. The mercury accumulation index for L. uniflorus was high, indicating that this species is an accumulator of mercury.

Lysimachia terrestris (loosestrife)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 3-36 ppm, mean = 10.2 ppm; not significantly correlated with arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.040-0.446 ppm, mean = 0.136 ppm; not significantly correlated with mercury concentrations in the soil.

*Lysimachia terrestris* was similar to *Lycopus uniflorus* in that it was found as a minor species in almost all tailings plant communities. This species was typically found growing on poorly drained tailings overlain by relatively thick layers of organic matter (Table 8). *Lysimachia* was found throughout the range of soil arsenic and mercury concentrations (Tables 9 and 10), suggesting that it is tolerant of large quantities of both elements. It was generally found on tailings containing high acid-extractable concentrations of arsenic and mercury. These tailings, however, contained only moderate concentrations of water-soluble arsenic and low concentrations of water-soluble mercury. The low availability of arsenic and mercury was probably attributable to binding of these elements to organic matter in the soil. Tissue concentrations of arsenic were low, while mercury tissue concentrations were moderate in comparison to other species. The arsenic accumulation index for *L. terrestris* was moderate in comparison to other species; however, the mercury accumulation index was high, indicating that this species was a good accumulator of mercury (Table 13).

### *Onoclea sensibilis* (sensitive fern)

Biomass: positively correlated with the concentration of total acid-extractable arsenic in the soil (Table 11).

Tissue Arsenic Concentrations: range = 3-32 ppm, mean = 5.40 ppm; positively correlated with the concentration of total acid-extractable arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.062-0.317 ppm, mean = 0.157 ppm; positively correlated with the concentration of total acid-extractable mercury and total water-soluble mercury in the soil (Table 14).

*Onoclea sensibilis* was found in a variety of plant communities, but it was most abundant in the shrub communities with well-developed leaf canopies, such as the tall *Alnus rugosa* - *Spiraea latifolia* and *Alnus rugosa* - *Acer rubrum* communities. *O. sensibilis* was most frequently encountered on fairly well-drained soils containing high concentrations of organic matter (Table 8). The biomass of this species was positively correlated with soil concentrations of arsenic. *O. sensibilis* may have benefited from reduced between-species competition on sites highly contaminated by arsenic.

*O. sensibilis* was found growing throughout the ranges of soil arsenic and mercury concentrations, indicating that it is tolerant of these elements. It was frequently found on soils containing high concentrations of mercury and acid-extractable arsenic (Tables 9 and 10). Concentrations of water-soluble arsenic in the tailings where this species was found tended to be moderate. Some accumulation of arsenic and mercury in the tissues appeared to take place as indicated by the positive correlations between tissue and soil concentrations of these elements; however, moderate tissue mercury concentrations and very low tissue arsenic concentrations suggest that the accumulation of these elements was limited. The arsenic and mercury accumulation indices were low, indicating that O. sensibilis tended to exclude both elements (Table 13).

Osmunda regalis (royal fern)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 3-8 ppm, mean = 4.20 ppm; not significantly correlated with any measurements of arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.036-0.102 ppm, mean = 0.077 ppm; not significantly correlated with any measurements of mercury concentrations in the soil.

This uncommon species was found in several of the herbaceous plant communities, generally on dry tailings containing low concentrations of organic matter (Table 8). The biomass of this species was positively correlated with the concentration of water-soluble arsenic in the soil. O. regalis was found within a relatively narrow range of soil arsenic concentrations (351-3470 ppm of total acid-extractable arsenic and 1.33-317 ppm of total water-soluble arsenic); however, the mean soil arsenic concentrations (acid-extractable and water-soluble) for the sites on which this species was most frequently found were moderate to high in comparison to sites at which other species were found (Table 9). The soil mercury concentrations for sites at which O. regalis was found tended to be high (Table 10). Tissue concentrations of arsenic and mercury were low in comparison to other species in spite of the fact that O. regalis grew in soils containing high concentrations of both of these elements. The arsenic and mercury accumulation indices were also low for this species (Table 13). This evidence suggests that O. regalis tolerates high concentrations of arsenic and mercury by means of exclusion.

Polytrichum commune (hair-cap moss)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 3-2360 ppm, mean = 420 ppm; not significantly correlated with arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.430-4.490 ppm, mean = 2.260 ppm; positively correlated with concentrations of total acid-extractable arsenic, in the soil (Table 14).

Polytrichum commune was relatively uncommon on the Oldham tailings. It was most frequently encountered on hummocks in openings or lightly shaded areas in shrub thickets. Unlike Campylium stellata, this moss species was often found growing on soils containing high concentrations of organic matter (Table 8). It occurred over the full range of soil arsenic and mercury concentrations, and was most frequently found growing on tailings containing very high concentrations of both arsenic and mercury (Tables 9 and 10). Soil mercury concentrations were positively correlated with tissue mercury concentrations, which were the highest recorded at Oldham. P. commune also had the second highest tissue arsenic concentrations. Arsenic and mercury accumulation indices were very high for P. commune, indicating that this species was a very effective accumulator of both arsenic and mercury (Table 13).

Prunella vulgaris (heal-all)

Biomass: positively correlated with the concentration of total water-soluble mercury in the soil (Table 11).

Tissue Arsenic Concentrations: range = 2-80 ppm, mean = 16.4 ppm; positively correlated with concentration of total acid-extractable arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.130-0.640 ppm, mean = 0.258 ppm; not significantly correlated with mercury concentrations in the soil.

Prunella vulgaris was generally restricted to the herbaceous communities, and was most abundant in the Equisetum fluviatile - Agrostis palustris community. P. vulgaris was typically found growing on well-drained tailings containing very low concentrations of organic matter and having high bulk density (Table 8). The tailings on which this species was most frequently found were characterized by low concentrations of acid-extractable arsenic and mercury, high concentrations of water-soluble arsenic, and moderate concentrations of water-soluble mercury (Tables 9 and 10). High availability of arsenic is often associated with sandy soils containing little clay or organic material to which arsenic can be adsorbed (21). Biomass was positively correlated with soil mercury concentrations, indicating that Prunella was tolerant of this element and probably gains a competitive advantage in highly contaminated areas. Tissue mercury concentrations were high; however, the mercury accumulation index for P. vulgaris was only moderate in comparison to other species (Table 13). Arsenic tissue concentrations were correlated with soil arsenic concentrations. Although only moderate arsenic concentrations were found in the tissues, the arsenic accumulation index for P. vulgaris was high.

Rubus pubescens (dewberry)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 2-132 ppm, mean = 16.1 ppm; positively correlated with the concentration of total water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.046-0.228 ppm, mean = 0.096 ppm; not significantly correlated with any measurements of mercury concentrations in the soil.

Rubus pubescens was found primarily as an understory herb in the shrub communities, achieving its greatest abundance in the tall Alnus rugosa-Spiraea latifolia community. R. pubescens is fairly tolerant of shade and, consequently, grew well under the Alnus rugosa canopy in the shrub communities. R. pubescens was characteristically found on well-drained tailings covered by a thick layer of organic matter (Table 8). This combination would provide a mesic environment compatible with good growth. R. pubescens was restricted to sites with relatively low concentrations of arsenic and mercury in the soil (Tables 9 and 10). This may indicate that this species is more sensitive to these elements than are other species. Tissue arsenic concentrations were positively correlated with soil arsenic concentrations, suggesting that some arsenic accumulation took place. Tissue arsenic concentrations in R. pubescens were moderate in comparison to other species, and tissue mercury concentrations were low. Arsenic and mercury accumulation indices were both low for R. pubescens, indicating that it accumulated only small quantities of these elements (Table 13).

### Solidago canadensis (Canada goldenrod)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 2-4 ppm, mean = 3.14 ppm; not significantly correlated with any measurements of arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.022-0.144 ppm, mean = 0.061 ppm; not significantly correlated with any measurements of mercury concentrations in the soil.

Solidago canadensis was a relatively uncommon species on the Oldham tailings but was found in a variety of herbaceous and shrub communities. It was most often found in areas where the soil contained moderate to high organic matter content and a fairly high water table (Table 11). This species was generally found growing on tailings containing low concentrations of arsenic and mercury (Tables 9 and 10). Tissue arsenic and mercury concentrations for this species were also very low. The arsenic accumulation index for this species was very low, indicating that this species tends to exclude this element (Table 13). The mercury accumulation index, however, was high as a result of an extremely high accumulation index value noted for a site having a very low concentration of water-soluble mercury. Data from other species also showed a tendency for accumulation rates to be high for plants growing in very low concentrations of arsenic or mercury. These results suggest that the affinity of plants for arsenic or mercury is high, but the amount that can be stored in the tissues is limited. The addition of relatively small quantities of arsenic or mercury to the soil results in high rates of accumulation; however, as soil concentrations increase, the relative amount of arsenic that can be accumulated in the tissues declines as the tissue concentrations approach their maximum levels. Solidago canadensis is, therefore, a very good mercury accumulator at low soil concentrations, but its capacity to store mercury in its tissues is very limited as is evident in the low tissue concentrations for this species.

Solidago rugosa (rough goldenrod)

Biomass: positively correlated with soil organic matter content and the concentration of total acid-extractable arsenic in the soil (Table 11).

Tissue Arsenic Concentrations: range = 2-3 ppm, mean = 2.33 ppm; not significantly correlated with any measurements of arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.002-0.054 ppm, mean = 0.041 ppm; not significantly correlated with any measurements of mercury concentrations in the soil.

Solidago rugosa was uncommon on the Oldham tailings and was found only in well-drained shrub communities. Best growth of this species was achieved at sites with a deep water table and a very high soil organic matter content (Table 8); hence, the positive correlation with soil organic matter content. High soil organic matter content would improve the water-holding ability of the soil and would provide a reservoir of essential nutrients, thereby creating a habitat much more amenable to plant growth than the bare tailings. S. rugosa tended to be found at sites whose soil contained low concentrations of both arsenic and mercury (Tables 9 and 10). Tissue arsenic and mercury concentrations were both extremely low, corresponding to background levels in plants from uncontaminated areas (6) (8). The arsenic accumulation index for this species was very low, indicating that S. rugosa has a very limited ability to take up this element (Table 13). The mercury accumulation index was quite high, being elevated in the same manner as the index for S. canadensis. Recalculation of the index without the extremely high value yielded a mean value of 0.61, which is within the low range. These results suggest that like S. canadensis, S. rugosa is a very good accumulator of mercury at low soil concentrations, but its capacity to store mercury is very limited.

Spiraea latifolia (hardhack)

Biomass: positively correlated with thickness of the organic matter layer, soil organic matter content, concentrations of total acid-extractable arsenic in the soil, total acid-extractable mercury in the soil, and total water-soluble mercury in the soil. Negatively correlated with weight of the soil sink fraction, and soil bulk density (Table 11).

Tissue Arsenic Concentrations: range in foliage = 2-100 ppm, mean =25.7 ppm; not significantly correlated with concentrations of arsenic in the soil.

Tissue Mercury Concentrations: range in foliage = 0.066-0.668 ppm, mean = 0.158 ppm; not significantly correlated with concentrations of mercury in the soil.

Spiraea latifolia was found in all of the tailings plant communities with the exception of the Chara globularis - Equisetum fluviatile community. It was most abundant in the shrub communities where it was co-dominant with Alnus rugosa. Best growth was found on well-drained soils with high organic matter content (Table 8). The distribution of S. latifolia on the tailings was not limited by arsenic or mercury concentrations in the soil, since it was found throughout the soil concentration ranges of these elements (Table 9 and 10 ). Biomass was positively correlated with concentrations of arsenic and mercury in the soil, indicating that this species was tolerant of these elements. It may also indicate that S. latifolia gains a competitive advantage in areas of suitable habitat highly contaminated by arsenic and mercury.

Tissue arsenic concentrations were fairly high in comparison to other species. The arsenic accumulation index for this species was moderate (Table 13), suggesting that S. latifolia is a weak accumulator of arsenic. Tissue mercury concentrations were moderate in comparison with other species, and the mercury accumulation index was moderate, indicating that S. latifolia was also a weak accumulator of mercury.

### Thalictrum polygamum (meadow-rue)

Biomass: no significant correlations between physical and chemical parameters and the biomass of this species.

Tissue Arsenic Concentrations: range = 2-10 ppm, mean = 4.50 ppm; not significantly correlated with any measurements of arsenic concentrations in the soil.

Tissue Mercury Concentrations: range = 0.028-0.200 ppm, mean = 0.083 ppm; positively correlated with the concentration of total water-soluble mercury in the soil (Table 14).

Thalictrum polygamum was found in several tailings plant communities, although it was not abundant in any of them. T. polygamum was noticeably stunted on the Oldham tailings, achieving less than 10% of the stature of plants found off the tailings. This stunting was probably attributable to a combination of heavy metal toxicity, seasonal droughtiness and poor mineral nutrition. This species was most often found in areas of the tailings where the water table was fairly close to the surface and where moderate amounts of organic matter had been incorporated into the soil (Table 8). Soil arsenic and mercury concentrations were low in areas where T. polygamum grew (Tables 9 and 10), suggesting that it may be more sensitive to these elements than most of the other species found on the tailings. This is consistent with the marked stunting noted for this species. Tissue mercury concentrations were correlated with concentrations of water-soluble mercury in the soil, indicating that some uptake of this element took place; however, the amounts taken up were quite low judging by the low tissue concentrations. Tissue concentrations of arsenic were also very low, falling within the range of tissue concentrations for plants found in uncontaminated areas. The arsenic and mercury accumulation indices for this species were both low (Table 13). These data suggest that T. polygamum deals with high soil arsenic and mercury primarily through exclusion.

Viola pallens (small white violet)

Biomass: positively correlated with the concentration of total water-soluble arsenic in the soil (Table 11).

Tissue Arsenic Concentrations: range = 5-560 ppm, mean = 119 ppm; positively correlated with the concentrations of total acid-extractable and water-soluble arsenic in the soil (Table 14).

Tissue Mercury Concentrations: range = 0.043-1.132 ppm, mean = 0.536 ppm; not significantly correlated with concentrations of mercury in the soil.

Viola pallens grew well under a variety of site conditions; consequently, it was found in all of the tailings plant communities with the exception of the Chara globularis - Equisetum fluviatile community. It was most abundant in the Equisetum arvense - Agrostis palustris and the Equisetum fluviatile - Agrostis palustris communities. The biomass of V. pallens was positively correlated with concentrations of arsenic in the soil, and it was found over the entire range of arsenic and mercury concentrations. It was most frequently found growing on tailings containing high concentrations of arsenic and moderate to high concentrations of mercury (Tables 9 and 10). These results indicate that it was tolerant of high concentrations of both elements, and that it may gain a competitive advantage in suitable habitat heavily contaminated with arsenic.

Tissue arsenic concentrations were very high and were highly positively correlated with soil arsenic concentrations. Tissue mercury concentrations were also very high, although they were not correlated with soil mercury concentration. V. pallens was an excellent accumulator of both arsenic and mercury. The arsenic accumulation index for this species was the third highest recorded in this study, and the mercury accumulation index was the fourth highest (Table 13).

In the following text some of the general results of the species habitat preference study are reviewed. The discriminant analysis determined that the most important factors determining the distribution of plant communities on the tailings were depth to water table and various measures of soil texture. It is reasonable to conclude that these two factors are very important in determining the distribution of individual species on the tailings. Although there was considerable overlap in the ranges of these parameters between species some trends were evident.

A number of species were typically found growing in soils having a high water table. These included Chara globularis (which was found only in permanent standing water), Carex brunessens, Hypericum virginicum, Juncus articulatus, Iris versicolor, Lysimachia terrestris and Equisetum fluviatile. Other species were characteristic of well drained tailings including Osmunda regalis, Aster lateriflorus, A. umbellatus, Chrysanthemum leucanthemum, Rubus pubescens and Solidago rugosa.

The various measures of soil texture yielded very similar results. For the sake of brevity only the species preferences for soil organic matter content are presented here. Species typically found growing in soil containing high concentrations of organic matter included Solidago rugosa, Juncus effusus, Alnus rugosa, Carex brunessens and Aster umbellatus. Species characteristic of bare tailings included Chrysanthemum leucanthemum, Prunella vulgaris, Equisetum variegatum, Osmunda regalis, Aster lateriflorus and Agrostis palustris.

Water soluble arsenic is generally considered to be a good indication of potential arsenic in soils (21). This is probably true for mercury as well. An indication of the tolerance of plants to these elements can be derived by observing the range of water soluble arsenic and mercury concentrations over which various species are found. Most species in this study were found over most of the ranges of water soluble arsenic and mercury concentrations suggesting that they were tolerant of these elements. Five out of 33 species were never found on tailings having more than 100 ppm of water soluble arsenic (out of a range of 1-745 ppm) suggesting that they were sensitive to arsenic. These species included Carex brunessens, Chara globularis, Iris versicolor, Solidago canadensis and S. rugosa. The occurrence of Chara globularis on tailings containing low concentrations of arsenic does not reflect a sensitivity to arsenic since this species was capable of accumulating up to 10,000 ppm of arsenic in its tissues. This species was restricted to areas of low arsenic concentration by its requirement of permanent standing water. Seven species were found only on tailings containing less than 0.1 ppm of mercury. These species included Carex brunessens, Chara globularis, Iris versicolor, Juncus effusus, Rubus pubescens, Solidago rugosa and Thalictrum polygamum.

Average concentrations of water soluble arsenic and mercury to the sampling sites where each species was found also provide an indication of the ability of a species to tolerate these elements. The lowest mean soil arsenic concentrations (least tolerant of arsenic) were noted for Chara globularis, Carex brunessens, Iris versicolor, Solidago rugosa, S. canadensis and Thalictrum polygamum. The lowest mean mercury concentrations were noted for Carex brunessens, Iris versicolor, Thalictrum polygamum, Chara globularis, Juncus effusus and Juncus articulatus. As mentioned earlier, the presence of Chara globularis in these lists is attributable to its requirement for permanent standing water rather than an intolerance of arsenic or mercury. The species which inhabited tailings with the highest average concentrations of water soluble arsenic (tolerant of arsenic) were Polytrichum commune, Equisetum variegatum, E. arvense, Aster novi-belgii and Eupatorium perfoliatum. The highest mean soil mercury concentrations were noted for

*Polytrichum commune*, *Aster lateriflorus*, *Onoclea sensibilis*, *Aster umbellatus* and *Campylium stellata*.

The highest tissue concentrations of arsenic were found in *Chara globularis*, *Polytrichum commune*, *Campyllium stellata*, *Viola pallens* and *Eupatorium perfoliatum*. Mercury tissue concentrations were highest in *Polytrichum commune*, *Campylium stellata*, *Viola pallens*, *Chara globularis* and *Equisetum arvense*. With the exceptions of *Eupatorium perfoliatum* and *Equisetum arvense* the same set of species were capable of accumulating large concentrations of both arsenic and mercury. The best accumulators were algae (*Chara*) and mosses (*Polytrichum* and *Campylium*). These taxa are noted for their high cation exchange capacity. They lack true roots and much of the nutrient and metal uptake takes place through their above-ground surfaces, consequently high concentrations may be expected in this portion of the plant. Much of the metal loadings in these species may be attributable to adsorption to plant surfaces rather than incorporation of metals into plant tissue by absorption. Metal concentrations in the above-ground portions of vascular plant were consistently lower than in the algae and mosses. Table 15 indicates that metal concentrations in the roots of vascular plants from the Oldham tailings were 4.4 to 17.0 times higher than in the shoots. Higher concentrations in the roots are probably attributable to the adsorption of arsenic to the epidermis of the root which is constantly exposed to water relatively rich in arsenic and mercury. Arsenic and mercury concentrations in whole vascular plants may be expected to be similar to those found in the algae and mosses.

Some species accumulated very little arsenic or mercury in their tissues. *Osmunda regalis*, *Solidago canadensis*, *S. rugosa* and *Thalictrum polygamum* never accumulated more than 10 ppm of arsenic in their above-ground tissues. The average tissue arsenic concentrations for these species ranged from 2.33 to 4.50 ppm. Plants from habitats uncontaminated by arsenic generally have tissue concentrations of 1-2 ppm (17). The soils on which these tailings species were found contained concentrations of arsenic many times higher than the normal concentration of arsenic in the soil which is less than 15 ppm (21). This suggests that these species are able to exclude arsenic from their tissues. All of these species with the exception of *Osmunda regalis* were generally restricted to tailings containing relatively low concentrations of water soluble (available) arsenic. These species probably have upper levels of tolerance which are higher than those of plants found off the tailings but lower than those of other species found on the tailings. Species highly tolerant of arsenic and able exclude it included *Osmunda regalis*, *Onoclea sensibilis*, *Aster lateriflorus* and *A. novi-belgii*.

Species which accumulated very low concentrations of mercury included *Carex brunessens*, *Iris versicolor*, *Solidago rugosa*, *S. canadensis* and *Thalictrum polygamum*. All of these species were found in soils whose mercury concentrations greatly exceeded the average of 0.081 ppm in uncontaminated soils in Canada (19). This implies exclusion of mercury from the tissues of these species, however, all of these species were restricted to the lower range of soil mercury concentrations on the tailings suggesting that they were not as tolerant of this element as other species. Species which maintained

Table 15. Concentrations of Arsenic and Mercury in shoots and roots of plant species associated with tailings deposits at Oldham.

| | Arsenic (ppm) | | Mercury (ppm) | |
|---|---|---|---|---|
| | Shoots | Roots | Shoots | Roots |
| _Equisetum_ _fluviatile_ | 700 | 3050 | 0.45 | 0.47 |
| _E_. _fluviatile_ uncontaminated* | 2 | - | - | - |
| _Juncus_ _articulatus_ | 580 | 6340 | 0.55 | 2.69 |
| _Juncus_ _pelocarpus_ | 330 | 5620 | 0.54 | 6.11 |
| _Dulichium_ _arundinaceum_ | 400 | 3110 | 0.19 | 0.67 |
| _Leersia_ _oryzoides_ | 321 | 2650 | 0.18 | 1.56 |

* From Dale and Freedman 1982

low tissue mercury concentrations while growing on soils high in mercury included *Aster lateriflorus*, *Osmunda regalis* and *Onoclea sensibilis*.

Table 16 represents an amalgamation of Tables 8 - 10 albeit considerably simplified. Mean values for each of the physical parameters have been reduced to a three level scale. This table presents the habitat preferences for the 33 species commonly found on the Oldham tailings. This condensed table and the tables containing the detailed information provide a useful means of selecting plant material for revegetation of disturbed or newly formed tailings deposits. One factor limiting the utility of this table is the fact that the data pertains to arsenic and mercury tolerant genotypes which have developed on the Oldham tailings. Other tailings areas may contain the same species, however, the tolerance of those species to arsenic and mercury may be quite different. Species capable of growth on tailings containing little organic matter would be most useful for the revegetation of disturbed or newly formed tailings. On dry tailings (average summer water table >17 cm deep), *Equisetum variegatum*, *Prunella vulgaris*, *Chrysanthemum leucanthemum*, *Aster lateriflorus* and *Osmunda regalis* would be expected to grow well as would species such as *Equisetum fluviatile*, *E. arvense* and *Agrostis palustris* which have very broad tolerances in terms of water table depth and soil organic matter content. Of these species only *E. arvense* would be expected to perform well if both arsenic and mercury soil concentrations were high. Under conditions of high soil arsenic and low to moderate soil mercury, *E. fluviatile*, *A. palustris*, *E. arvense*, *E. variegatum* and *P. vulgaris* would be expected to grow well. Species capable of growing well under conditions of high soil mercury and low to moderate soil arsenic would include *E. arvense*, *A. lateriflorus* and *O. regalis*.

In mesic areas (average summer water table = 12-17 cm deep) containing little organic matter *Eupatorium perfoliatum*, *Aster novi-belgii*, *Centaurea nigra*, *Agrostis palustris* as well as *Equisetum fluviatile* and *E. arvense* would be expected to grow well. *E. fluviatile*, *E. arvense*, *E. perfoliatum*, *A. palustris*, and *A. novi-belgii* would be capable of growing on tailings containing high concentrations of soil arsenic while only *E. arvense* would grow well if the tailings contained high concentrations of mercury.

In wet areas (average summer water table <12 cm deep) containing little organic matter *E. fluviatile* and *Chara globularis* could be grown. Both species are highly tolerant of arsenic and *C.globularis* is also capable of accumulating large concentrations of mercury (in spite of the fact that it was found in an area characterized by low soil concentrations of arsenic and mercury). Growth of *C. globularis* would be restricted to permanently flooded areas. *C. globularis* also prefers waters with relatively high pH so the acidity of the surface water would have to be considered before choosing this species.

Species typical of areas with moderate to high organic matter content would probably require the addition of fertilizer or organic matter in the form of manure, sewage sludge, peat on forest floor duff to bare tailings to permit maximum growth. Some species such as *Juncus articulatus*, *Viola pallens* and *Campylium stellata* can survive on tailings with low organic matter content, and could be planted with species tolerant of low soil organic

Table 16. Habitat preferences for common species on the Oldham tailings, low, moderate and high ranges were derived from the distributions of averages for each of the species for each of the parameters.

|  | Depth to Water Table | Soil Organic Matter Content | Water Soluble As in the soil | Water Soluble Hg in the soil |
|---|---|---|---|---|
| Low range | >12 cm | >7% | >50 ppm | >0.044 ppm |
| Moderate range | 12-17 cm | 7-14% | 50-63 ppm | 0.004-0.052 p m |
| High range | <17 cm | <14% | <63 ppm | <0.052 ppm |
| Species |  |  |  |  |
| Chara globularis | Low | Low | Low | Low |
| Iris versicolor | Low | Moderate | Low | Low |
| Solidago canadensis | Low | Moderate | Low | Low |
| Thalictrum polygamum | Low | Moderate | Low | Low |
| Juncus articulatus | Low | Moderate | Moderate | Low |
| Carex viridula | Low | Moderate | Moderate | Low |
| Lysimachia terrestris | Low | Moderate | Moderate | Low |
| Equisetum fluviatile | Low | Moderate | High | Moderate |
| Carex brunessens | Low | High | Low | Low |
| Juncus effusus | Low | High | Low | Low |
| Hypericum virginicum | Low | High | Moderate | Low |
| Centaurea nigra | Moderate | Low | Moderate | Moderate |
| Eupatorium perfoliatum | Moderate | Low | High | Moderate |
| Agrostis palustris | Moderate | Low | High | Moderate |
| Aster novi-belgii | Moderate | Low | High | Moderate |
| Lycopus uniflorus | Moderate | Moderate | Low | Moderate |
| Campylium stellata | Moderate | Moderate | Moderate | High |
| Viola pallens | Moderate | Moderate | High | Moderate |
| Alnus rugosa | Moderate | High | Low | Moderate |
| Onoclea sensibilis | Moderate | High | Moderate | High |
| Chrysanthemum leucanthemum | High | Low | Low | Moderate |
| Aster lateriflorus | High | Low | Moderate | High |
| Osmunda regalis | High | Low | Moderate | High |
| Equisetum variegatum | High | Low | High | Moderate |
| Prunella vulgaris | High | Low | High | Moderate |
| Rubus pubescens | High | Moderate | Low | Low |
| Equisetum arvense | High | Moderate | High | High |
| Dryopteris thelypteris | High | Moderate | High | High |
| Solidago rugosa | High | High | Low | Low |
| Aster umbellatus | High | High | Moderate | High |
| Spiraea latifolia | High | High | Moderate | High |
| Polytrichum commune | High | High | High | High |

matter, so that, as organic matter builds up, these species would be available to colonize it. V. pallens is highly tolerant of arsenic while C. stellata is highly tolerant of mercury. C. stellata would be particularly useful since it produces an almost continuous mat of vegetation which would help to reduce transport of arsenic and mercury by means of erosion. Nitrogen fixers such as Alnus rugosa would help to alleviate nitrogen deficiencies on tailings sites but would probably require an initial applications of organic matter to ameliorate seasonal water stress and provide other essential nutrients. Once established, however, it would contribute large quantities of organic matter to the soil which would help to further ameliorate water and nutrient stress and provide a sink for free arsenic and mercury in the soil.

## 5.0 CONCLUSIONS

The most significant finding of the tailings analyses is the high and consistent amount of mercury. Mercury distribution is controlled by:

a) tailings grain size (the finest grain portions of a tailings profile tend to be more mercury-rich),

b) grade of tailings (tailings associated with ore-grade areas are more mercury-rich),

c) amount of fine-grained organic matter (the more organic rich samples, especially in generally fine-grained tailings tend to be more mercury-rich).

Arsenic concentration and distribution are controlled by arsenopyrite distribution in subsurface samples. Redistribution into the fine organic or clay fraction was evident for samples taken from the tailings surface. Relatively little of the total arsenic and mercury in the tailings was available for plant uptake. Seven percent of total soil arsenic and two percent of total soil mercury were released by artificial leaching of the tailings. The data suggest that arsenic in the surface tailings was bound more tightly to the soil float fraction (clay and organic matter) than to the soil sink fraction (sandy tailings). The opposite trend was noted for mercury.

The groundwater chemistry of the tailings is characterized by concentrations of arsenic, iron and manganese in excess of recommended values, but relatively little free mercury. The tailings contribute enough arsenic to Black Brook to increase downstream concentrations beyond safe limits; however, the buffering action of the tailings helps to alleviate the acid drainage problem experienced by this brook. The vegetation of the site appears to be composed largely of genotypes of relatively common species capable of tolerating high concentrations of both arsenic and mercury. The algae and moss species tested accumulated very high concentrations of both metals, which may reflect both active metal uptake and passive adsorption of arsenic and mercury onto their surfaces.

A total of ten plant communities were noted in the tailings deposits. The most important physical features of the tailings environment determining the distribution of plant communities on the tailings were depth to water table and the texture of the tailings as measured by organic matter content and soil bulk density. Arsenic and mercury concentrations appeared to have little influence on the distribution of tailings plant communities although they were often present in very high concentrations. The apparent lack of influence of these metals on plant community development on the tailings may be attributable to the fact that most of the species present on the tailings were highly tolerant of arsenic and mercury contamination.

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# Appendix 1

## Results of one-way analysis of variance and Student-Newman-Keuls multiple-range tests for between plant community comparisons of chemical and physical parameters

## Table 1

Matrices of the Student-Newman-Keuls multiple range test results for values of water table depth for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | * | | | | | | | | | |
| Cluster 3 | * | * | | | | | | | | |
| Cluster 4 | * | * | | | | | | | | |
| Cluster 5 | * | * | | | | | | | | |
| Cluster 6 | * | * | | | | | | | | |
| Cluster 7 | * | * | | | | | | | | |
| Cluster 8 | * | * | | | | | | | | |
| Cluster 9 | * | * | | | | | | | | |
| Cluster 10 | * | * | | | | | | | | |
| Cluster 11 | * | * | | | | | | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 7.58 | <0.001 | 10 |

## Table 2

Matrices of the Student-Newman-Keuls multiple range test results for values of thickness of organic matter layer for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | * | | | | | | | | | |
| Cluster 3 | | * | | | | | | | | |
| Cluster 4 | | | | | | | | | | |
| Cluster 5 | | * | | | | | | | | |
| Cluster 6 | | | | | | | | | | |
| Cluster 7 | * | | * | | | | | | | |
| Cluster 8 | * | | * | | * | | | | | |
| Cluster 9 | * | | * | | * | | | | | |
| Cluster 10 | * | * | * | * | * | * | | | | |
| Cluster 11 | * | | * | | * | | | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 6.57 | <0.001 | 10 |

Table 3

Matrices of the Student-Newman-Keuls multiple range test results for values of soil organic matter content for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

Multiple-range Test Results

Cluster

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | | |
| Cluster 3 | | | | | | | | | | | |
| Cluster 4 | | | | | | | | | | | |
| Cluster 5 | | | | | | | | | | | |
| Cluster 6 | | | | | | | | | | | |
| Cluster 7 | | | | | | | | | | | |
| Cluster 8 | | * | * | * | * | * | | | | | |
| Cluster 9 | * | * | * | * | * | * | * | | | | |
| Cluster 10 | * | * | * | * | * | * | * | * | * | | |
| Cluster 11 | | | * | | | | | | | * | |

One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 9.70 | <0.001 | 10 |

Table 4

Matrices of the Student-Newman-Keuls multiple range test results for values of the weight of the soil float fraction for each plant community. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

Multiple-range Test Results

|  | Cluster |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 |  |  |  |  |  |  |  |  |  |  |
| Cluster 2 | * |  |  |  |  |  |  |  |  |  |
| Cluster 3 | * |  |  |  |  |  |  |  |  |  |
| Cluster 4 | * |  |  |  |  |  |  |  |  |  |
| Cluster 5 | * |  |  |  |  |  |  |  |  |  |
| Cluster 6 | * |  |  |  |  |  |  |  |  |  |
| Cluster 7 | * |  |  |  |  |  |  |  |  |  |
| Cluster 8 | * |  |  |  |  |  |  |  |  |  |
| Cluster 9 | * |  |  |  |  |  |  |  |  |  |
| Cluster 10 |  |  |  |  |  |  |  |  |  |  |
| Cluster 11 | * |  |  |  |  |  |  |  |  |  |

One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 2.67 | 0.006 | 10 |

## Table 5

Matrices of the Student-Newman-Keuls multiple range test results for values of the weight of the soil sink fraction for each plant community. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | * | * | | | | | | | | |
| Cluster 4 | * | * | | | | | | | | |
| Cluster 5 | * | * | | | | | | | | |
| Cluster 6 | * | * | | | | | | | | |
| Cluster 7 | | | * | * | * | * | | | | |
| Cluster 8 | | | * | * | * | * | | | | |
| Cluster 9 | | | * | * | * | * | | | | |
| Cluster 10 | | | * | * | * | * | | | | |
| Cluster 11 | | | | * | * | * | * | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 8.88 | <0.001 | 10 |

## Table 6

Matrices of the Student-Newman-Keuls multiple range test results for values of the weight of coarse organic matter for each plant community. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | | | | | | | | | | |
| Cluster 4 | | | | | | | | | | |
| Cluster 5 | | | | | | | | | | |
| Cluster 6 | | | | | | | | | | |
| Cluster 7 | | | | | | | | | | |
| Cluster 8 | | | * | * | | * | * | | | |
| Cluster 9 | | | | | | | | | | |
| Cluster 10 | | | * | * | | * | * | | | |
| Cluster 11 | | | | | | | | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 3.97 | <0.001 | 10 |

Table 7

Matrices of the Student-Newman-Keuls multiple range test results for values of soil bulk density for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

Multiple-range Test Results

| | Cluster | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | * | * | | | | | | | | |
| Cluster 4 | * | * | | | | | | | | |
| Cluster 5 | * | * | | | | | | | | |
| Cluster 6 | * | * | | | | | | | | |
| Cluster 7 | | | * | * | * | * | | | | |
| Cluster 8 | | | * | * | * | * | | | | |
| Cluster 9 | | | * | * | * | * | | | | |
| Cluster 10 | | | * | * | * | * | | | | |
| Cluster 11 | | | * | * | * | * | | | | |

One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 8.79 | <0.001 | 10 |

## Table 8

Matrices of the Student-Newman-Keuls multiple range test results for values of acid extractable arsenic in the soil float fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

No two communities were significantly different at the 0.05 level.

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 1.21 | 0.292 | 10 |

# Table 9

Matrices of the Student-Newman-Keuls multiple range test results for values of acid extractable arsenic in the soil sink fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

## Multiple-range Test Results

|  | Cluster |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 |  |  |  |  |  |  |  |  |  |  |
| Cluster 2 |  |  |  |  |  |  |  |  |  |  |
| Cluster 3 |  |  |  |  |  |  |  |  |  |  |
| Cluster 4 |  |  |  |  |  |  |  |  |  |  |
| Cluster 5 |  |  |  |  |  |  |  |  |  |  |
| Cluster 6 |  |  |  |  |  |  |  |  |  |  |
| Cluster 7 |  |  |  |  |  |  |  |  |  |  |
| Cluster 8 |  |  |  |  |  |  |  |  |  |  |
| Cluster 9 |  |  |  |  |  |  |  |  |  |  |
| Cluster 10 |  |  |  |  |  |  |  |  |  |  |
| Cluster 11 |  | * | * |  |  |  |  | * |  |  |

## One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 2.28 | 0.018 | 10 |

Table 10

Matrices of the Student-Newman-Keuls multiple range test results for values of total acid extractable arsenic in the soil for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

Multiple-range Test Results

No two communities were significantly different at the 0.05 level.

One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 1.45 | 0.170 | 10 |

## Table 11

Matrices of the Student-Newman-Keuls multiple range test results for values of acid extractable mercury in the soil float fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | | | | | | | | | | |
| Cluster 4 | | | | | | | | | | |
| Cluster 5 | | | | | | | | | | |
| Cluster 6 | * | * | * | | | | | | | |
| Cluster 7 | | | | | | | | | | |
| Cluster 8 | | | | * | | * | | | | |
| Cluster 9 | | | | | | | | | | |
| Cluster 10 | | | * | * | | * | | | | |
| Cluster 11 | | | | | | | | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 4.34 | <0.001 | 10 |

Table 12

Matrices of the Student-Newman-Keuls multiple range test results for values of acid extractable mercury in the soil sink fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

No two communities were significantly different at the 0.05 level.

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 2.57 | 0.008 | 10 |

## Table 13

Matrices of the Student-Newman-Keuls multiple range test results for values of total acid extractable mercury in the soil for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

No two communities were significantly different at the 0.05 level.

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 2.48 | 0.010 | 10 |

## Table 14

Matrices of the Student-Newman-Keuls multiple range test results for values of water soluble arsenic in the soil float fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

No two communities were significantly different at the 0.005 level.

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 1.64 | 0.104 | 10 |

## Table 15

Matrices of the Student-Newman-Keuls multiple range test results for values of water soluble arsenic in the soil sink fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

|  | Cluster |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 |  |  |  |  |  |  |  |  |  |  |
| Cluster 2 |  |  |  |  |  |  |  |  |  |  |
| Cluster 3 |  |  |  |  |  |  |  |  |  |  |
| Cluster 4 |  |  |  |  |  |  |  |  |  |  |
| Cluster 5 |  |  |  |  |  |  |  |  |  |  |
| Cluster 6 |  | * | * |  |  |  |  |  |  |  |
| Cluster 7 |  |  |  |  |  |  |  |  |  |  |
| Cluster 8 |  |  |  |  |  |  |  |  |  |  |
| Cluster 9 |  |  |  |  |  |  |  |  |  |  |
| Cluster 10 |  |  |  |  |  |  |  |  |  |  |
| Cluster 11 |  |  |  |  |  |  |  |  |  |  |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 1.71 | 0.087 | 10 |

## Table 16

Matrices of the Student-Newman-Keuls multiple range test results for values of total water soluble arsenic in the soil for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

Cluster

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 |  |  |  |  |  |  |  |  |  |  |
| Cluster 2 |  |  |  |  |  |  |  |  |  |  |
| Cluster 3 |  |  |  |  |  |  |  |  |  |  |
| Cluster 4 |  |  |  |  |  |  |  |  |  |  |
| Cluster 5 |  |  |  |  |  |  |  |  |  |  |
| Cluster 6 |  |  | * |  |  |  |  |  |  |  |
| Cluster 7 |  |  |  |  |  |  |  |  |  |  |
| Cluster 8 |  |  |  |  |  | * |  |  |  |  |
| Cluster 9 |  |  |  |  |  |  |  |  |  |  |
| Cluster 10 |  |  |  |  |  |  |  |  |  |  |
| Cluster 11 |  |  |  |  |  |  |  |  |  |  |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 1.31 | 0.232 | 10 |

# Table 17

Matrices of the Student-Newman-Keuls multiple range test results for values of water soluble mercury in the soil float fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

Multiple-range Test Results

Cluster

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | | | | | | | | | | |
| Cluster 4 | | | | | | | | | | |
| Cluster 5 | | | | | | | | | | |
| Cluster 6 | | * | | | | | | | | |
| Cluster 7 | | | | | | | | | | |
| Cluster 8 | | | | | | * | | | | |
| Cluster 9 | | | | | | | | | | |
| Cluster 10 | | | | | | * | | | | |
| Cluster 11 | | | | | | | | | | |

One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 1.97 | 0.044 | 10 |

## Table 18

Matrices of the Student-Newman-Keuls multiple range test results for values of water soluble mercury in the soil sink fraction for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | | | | | | | | | | |
| Cluster 4 | | | | | | | | | | |
| Cluster 5 | | | | | | | | | | |
| Cluster 6 | | * | | | | | | | | |
| Cluster 7 | | | | | | | | | | |
| Cluster 8 | | | | | | | | | | |
| Cluster 9 | | | | | | | | | | |
| Cluster 10 | | | | | | | | | | |
| Cluster 11 | | | | | | | | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 2.39 | 0.013 | 10 |

## Table 19

Matrices of the Student-Newman-Keuls multiple range test results for values of total water soluble mercury in the soil for each of the plant communities. Plant communities are identified by their cluster number. Significant differences between communities (0.05 level of significance) are indicated by asterisks. Results of the one-way analysis of variance between communities are also presented.

### Multiple-range Test Results

| | Cluster | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Cluster 1 | | | | | | | | | | |
| Cluster 2 | | | | | | | | | | |
| Cluster 3 | | | | | | | | | | |
| Cluster 4 | | | | | | | | | | |
| Cluster 5 | | | | | | | | | | |
| Cluster 6 | | * | | | | | | | | |
| Cluster 7 | | | | | | | | | | |
| Cluster 8 | | | | | | | | | | |
| Cluster 9 | | | | | | | | | | |
| Cluster 10 | | | | | | | | | | |
| Cluster 11 | | | | | | | | | | |

### One-way Analysis of Variance Results

| F ratio | F probability | Degrees of Freedom |
|---|---|---|
| 2.21 | 0.022 | 10 |